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The effects of prior moderate and intense exercise on sports-related performance

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THE EFFECTS OF PRIOR MODERATE
AND INTENSE EXERCISE ON
SPORTS-RELATED PERFORMANCE

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Glossary of key terms

The following key terms and definitions are referred to in this thesis:

Anaerobic capacity - the maximal amount of adenosine triphosphate resynthesised via anaerobic metabolism (by the whole organism) during a specific mode of short-duration maximal exercise (Green & Dawson, 1993).

Attentional focus - the ability to focus despite irrelevant environmental disturbances (Nougier, Stein & Bonnel, 1991).

Arousal - one's level of alertness that is placed on a continuum from very low activation to very high activation. The arousal state may be viewed as positive or negative and is accompanied by certain physiological responses regardless of the stimulus that evokes the condition (Oxendine, 1984).

Coincidence-anticipation timing - the ability to predict the arrival of a moving object at a particular point in space and coordinate a movement response with that arrival (Payne, 1986).

Co-ordination - a skill-related component of fitness that relates to the ability to use the senses, such as sight and hearing, together with body parts in performing motor tasks smoothly and accurately (Caspersen, Powell & Christenson, 1985).

Expert - one whose performance shows consummate skill and economy of effort and special skills or knowledge derived from extensive experience with sub-domains (Hoffman, 1996).

Fatigue - the state of an organism's muscles, viscera, or CNS, in which prior physical activity and/or mental processing, in the absence of sufficient rest, results in insufficient cellular capacity or system wide energy to maintain the original levels of activity and/or processing by using normal resources (Job & Dalziel, 2001).

Motivation - a hypothetical construct traditionally used to describe and explain differences in intensity and direction of behaviour (Humphreys & Revelle, 1984).

Muscular strength - a health-related component of physical fitness that relates to the amount of external force that a muscle can exert (Caspersen, Powell & Christenson, 1985).

Physical Fitness - a state characterised by (a) an ability to perform daily activities with vigor, and (b) demonstration of traits and capacities that are associated with low risk of premature development of the hypokinetic diseases (i.e. those associated with physical inactivity) (Pate, 1988).

Power - a skill-related component of physical fitness that relates to the rate at which one can perform work (Caspersen, Powell & Christenson, 1985).

Reaction time - a skill-related component of physical fitness that relates to the time elapsed between stimulation and the beginning of the reaction to it (Caspersen, Powell & Christenson, 1985).

Skill - the learned ability to bring about pre-determined results with maximum certainty often with the minimum outlay of time, energy or both (Knapp, 1963).

Speed - a skill-related component of physical fitness that relates to the ability to perform a movement within a short period of time (Corbin et al., 1978).

Abstract

The main aim of this research was to develop a greater understanding of the effects of prior moderate and intense exercise on sports-related performance. The research developed through five related studies that examined the effects of exercise on key aspects of sports performance. Each study was conducted in appropriate field-based settings, using protocols that have relevance to the chosen sports and performance tasks that display ecological validity. Three intensities were examined across each of the five studies; rest, moderate and intense exercise.

The preliminary study explored the effects of moderate and intense exercise on soccer passing performance in collegiate level players (n = 20). Repeated measures ANOVA revealed a significant ($p = 0.010$) effect of prior exercise on passing performance. Following on from this investigation, the effects of prior exercise on basketball passing performance in expert (n = 10) and non-expert players (n = 10) was examined. A 3 x 2 mixed ANOVA revealed a highly significant exercise intensity effect ($p < 0.001$) as well as a highly significant exercise intensity by level of expertise interaction ($p = 0.010$). No between-group differences were observed however. This study nevertheless revealed that the expert players maintain a better level of performance compared to non-expert players following moderate and high-intensity exercise conditions.

The third study explored the effects of moderate and intense exercise on coincidence-anticipation timing in expert (n = 11) and non-expert (n = 9) Gaelic games players. The 3 x 2 mixed ANOVA revealed no overall exercise intensity effect (p > 0.05) but there was a significant exercise intensity by level of expertise interaction ($p = 0.031$). Highly significant between-group differences ($p < 0.001$) were found, with the expert players maintaining a higher level of anticipation following moderate and intense exercise conditions.

Study four comprised a small-scale study (n = 12) examining the effects of moderate and intense exercise on attention using the Stroop Colour-Word Test. Repeated measures ANOVA revealed a significant (*p* = 0.030) effect of prior exercise on attention. This study identified that attention following moderate-intensity exercise is equivalent to that at rest. However, following intense exercise attention deteriorates to a level below that at rest. The final study examined the effects of exercise intensity on groundstroke accuracy in expert (n = 13) and non-expert (n = 17) tennis players and comprised the most ecologically valid design. A range of 3 x 2 mixed ANOVAs were conducted revealing highly significant ($p < .001$) main effects for exercise intensity as well as highly significant ($p = 0.003$) between-group effects. No exercise intensity by level of expertise interaction was found however. In general, the findings suggest that performance following moderate-intensity exercise is equivalent to that at rest. However, significant decrements in key aspects of sports-related performance were observed following intense exercise.

The findings of this research indicate that the theories of arousal cannot by themselves account for the outcomes of this work and the relationship between exercise and arousal needs to be explored further. Future research is imperative employing ecologically valid protocols and sport-specific performance tasks. The ensuing results in this case will have much more application and relevance to trainers, coaches and players.

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Preface

Research reported in this thesis has led directly to the following publications and presentations:

Al-Nakeeb, Y. and Lyons, M. (2005) Performance of a cognitive task following physical exertion. In: Proceedings of the 10th Annual Congress of the European College of Sport Science, 13-16th July, Belgrade, Serbia.

Lyons, M. and Al-Nakeeb, Y. (2004) Performance of soccer passing skills under moderate and high-intensity localised muscle fatigue. In: Proceedings of the 9th Annual Congress of the European College of Sport Science, 3-6th July, Clermont-Ferrand, France.

Lyons, M., Al-Nakeeb, Y. and Nevill, A. (2005) The impact of moderate and high-intensity total body fatigue on passing accuracy of experienced and novice basketball players. In: Proceedings of the 10th Annual Congress of the European College of Sport Science, 13-16th July, Belgrade, Serbia.

Lyons, M., Al-Nakeeb, Y. and Nevill, A. (2005) The effect of moderate and high-intensity fatigue on coincidence-anticipation in expert and novice Gaelic games players. In: Proceedings of the 2005 BASES Annual Conference, 4-7th Sept, Loughborough, United Kingdom.

Lyons, M., Al-Nakeeb, Y., Hankey, J. and Nevill, A. (2011) Groundstroke accuracy under moderate and high-intensity fatigue in expert and non-expert tennis players. In: Proceedings of the 58th Annual Congress of the American College of Sports Medicine, 31st May - 4th June, Denver, Colorado.

Lyons, M., Al-Nakeeb, Y. and Nevill, A. (2006) Performance of soccer passing skills under moderate and high-intensity localised muscle fatigue. *Journal of Strength and Conditioning Research* 20 (1): 197-202.

Lyons, M., Al-Nakeeb, Y. and Nevill, A. (2006) The impact of moderate and high-intensity total body fatigue on passing accuracy of experienced and novice basketball players. *Journal of Sport Science and Medicine* 5, 215-227.

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1.0 INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Fatigue is a topic that has fascinated exercise physiologists, psychologists, sport scientists, researchers and coaches alike for much of the 20th century. To the participant who has engaged in intense and sustained exercise, the symptoms of fatigue often represent a humiliating and distasteful experience. To the physiologist however, this behaviour is intriguing and challenging (Green, 1997). It is intriguing because of the severe insult imposed by this form of exercise on a wide range of physiological systems. It is challenging because of the difficulty in isolating the mechanisms for the inability to sustain performance among a complexity of changes in the multiple systems, organs, tissues and cells of the body (Green, 1990). Fatigue is multifaceted, complex and it encompasses a variety of behaviours that are unique to each situation (Gawron, French & Funke, 2001). The likelihood that deterioration in such a wide spectrum of motor behaviour can be traced to a single common event or process and mediated by some singular disturbance therefore, appears naïve (Green, 1990). Consequently, for the researcher trying to unravel the mechanistic basis of fatigue in skeletal muscle, the task is one of substantial proportions.

Fatigue, despite its practical importance within areas of industry such as ergonomics and transportation is especially important in a sporting context, reducing muscular performance, increasing the potential for injury and having a major effect on sporting outcomes. According to some authors (Bompa, 2000) fatigue is the single most detrimental factor to performance in sport. Athlete's who cannot cope effectively with fatigue, have a high probability of performing poorly and losing the game, race or match. Fatigue also affects the ability to concentrate, resulting in technical and tactical mistakes and throwing or shooting accuracies (Bompa, 2000). Differences in the level of fatigue of individuals within a team game may determine which player gets to the ball first, thereby dictating subsequent play and possibly the final result of a match (McKenna, 2003). In an individual sport, fatigue may be the determining factor between just beating an opponent and thus producing a gold or silver medal performance, or winning the vital final set in a tennis match.

In sport, and particularly as a match draws to its final stages, an athlete's skill level is often seen to deteriorate, with coaches and commentators tending to blame this decline on increasing exertion levels (Royal, 2004). However, physiologists, researchers and sport scientists alike are concerned with the validity of such statements. Chmura and Jusiak (1994) showed this to be the case and noted that homeostasis disturbances are frequently observed in the second half of games leading to mounting central and peripheral fatigue. More recently, Mohr, Krustrup and Bangsbo (2003) examined the physiological requirements of soccer and found that players experience temporary periods of fatigue during a match.

Within the scientific literature there is substantial support for the notion that players will experience temporary periods of fatigue. Many team sports provide conditions that challenge both perceptual and physical skills within a constantly changing environment and amplify the challenge of executing skills in a technically effective manner (Devlin et al., 2001). Furthermore, in many sports, players have to perform simultaneously, a physical, perceptual or decisional task under great physical exertion (Godefroy et al., 2002).

Despite the acknowledged importance of fatigue on sports performance and outcome, very little research has examined the effect of fatiguing exercise on the performance of sports skills (McMorris, 2004). This is surprising given the fact that within sports teams, especially in the modern era, there is continuing emphasis on performance quality and understanding the factors that mediate performance. Consequently, the effects of fatiguing exercise on sports performance is a topic that clearly merits further investigation.

1.2 Definition of fatigue

To understand what fatigue is better and how it influences sports performance, it is essential to define fatigue. Currently, there is a wide and diverse array of definitions of the term "fatigue" among the scientific disciplines (Abbiss & Laursen, 2006). This relates in part to the fact that fatigue has many connotations, with individuals using the term to refer to feelings of being tired, overworked and bored. Fatigue has also been used synonymously with terms such as physical exercise, physical exertion, stress and work-rate. In many studies, fatigue and other terms such as physical exertion/exercise are used interchangeably within the same paper (e.g. Royal, 2004). Consequently, while everyone has a notion of what constitutes fatigue (MacIntosh & Rassier, 2002) this creates potential for confusion. Regrettably, a universally accepted definition of fatigue is lacking and the ambiguous and complex nature of fatigue is perpetuated by the lack of a formal definition. A standard measurement of fatigue and fatigue states is also lacking (Fairclough, 2001). Some researchers, as early as the 1920's even proposed abandoning the concept of fatigue altogether (Muscio, 1921). This sentiment was reiterated by Forbes in 1943. Their justification was that no test can validly assess fatigue, since there is no definite observable criterion. Despite the fact that there is still no agreement today on the definition of fatigue, the most frequently referenced definitions will be briefly outlined here.

Earlier definitions of fatigue defined it as a process wherein past demand for exertion decreases the capability of the muscles to contract (Chaffin, 1969). Tatakuwa (1971) defined fatigue as the combined output of mental activity and physiological functions (Tatakuwa 1971, as cited in Hogervorst et al., 1996). Spano and Burke (1976, p.63) defined general fatigue as "the state of the body characterised by weariness, during which there is a clearly differentiated increase in perception of exertion". More recently, fatigue has been defined as the negative results or unpleasant experiences of prolonged or intense behaviour, regardless of whether the activity is fun or tedious (Craig & Cooper, 1992). Unfortunately, these broad definitions do not effectively capture the essence of fatigue, have plagued the scientific literature and so will not be adopted in this work.

Green (1990, p.14) points out that muscular fatigue is most frequently operationally defined as "the inability to generate a required or expected force". With this definition, a specific force criterion is established, and fatigue is defined as the point at which a particular force can no longer be maintained. Similar to this, McMorris et al. (1994)

used Edwards' (1983) definition of fatigue as the inability to maintain the required or expected power output. According to Edwards' (1983) definition, fatigue results in a total breakdown in performance. This may only be true if the criterion task is also the task in which the fatigue is induced. This definition has been widely used in research examining the effect of fatigue on cognitive and motor performance (Bard & Fleury, 1978; Fleury et al., 1981; Fleury & Bard, 1990; McMorris & Keen, 1994; Smilios, 1998; Mohr, Krustrup & Bangsbo, 2005). Other authors have suggested that this definition is more pertinent to sport than other definitions which are more suited to research on fatigue in the workplace (McMorris et al., 1994).

Fatigue is often defined as a reduction in capacity for force development (Fitts & Holloszy, 1976; Bigland-Ritchie, Cafarelli & Vøllestad, 1986). This definition has also been used by more recent researchers on this topic (Hunter, Duchateau & Enoko, 2004). However, this definition implies that fatigue does not occur until an individual is unable to continue exercising and, in effect, makes fatigue indistinguishable from exhaustion (Lewis & Fulco, 1998). Additionally, to identify the presence of fatigue by this definition, it is necessary to maximally activate a muscle because that is the only way to quantify the "capacity" for force development. Practically this is very difficult indeed (MacIntosh & Rassier, 2002) and arguably, inappropriate when the emphasis is exploring the effects of fatigue on sports-related performance.

In contrast to most definitions in the literature which define fatigue in a general sense, Pedersen et al. (1999, p.1047) defined localised muscle fatigue as an acute impairment in performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force. Another commonly used definition identifies fatigue as any reduction in a person's ability to exert force or power in response to voluntary effort, regardless of whether or not the task itself can still be performed successfully (Bigland-Ritchie & Woods, 1984). This definition has also been adopted by other researchers (Walsh, 2000: Enoko & Stuart, 1992). Finally, McCully et al. (2002, p.71) defined fatigue as the development of less than the expected amount of force as a consequence of muscle activation.

A perusal of the definitions here shows that while some definitions in the past have common elements, others are very dissimilar with different emphases. It is hardly surprising therefore, given the range of definitions provided here, that there is still no agreement on the definition of fatigue today. One common misconception, according to Brown (1994) is that fatigue is defined in terms of its consequences and is not recognised as a state of being. In an attempt to address this conceptual inconsistency, Job and Dalziel (2001) set out a series of "essential features" that all definitions of fatigue should include. They argued that fatigue must be viewed as a hypothetical construct; it is a state of the individual, not a feature of his/her behaviour or a performance outcome. In other words, reduced performance effectiveness/efficiency is not fatigue, but fatigue may lead to such results. An adequate definition should also identify the cause, not solely the result of the state. Fatigue should include a description of the conditions that arise in either the muscles or the central nervous system (CNS) that contribute to the onset of fatigue. Definitions of fatigue should avoid extremely technical language so that the description fits within the general population's logical conception of fatigue. Finally, they stated that the definition should be adequate so that fatigue can be distinguished from other related phenomena. Consequently, Job and Dalziel (2001, p.469) put forth their definition of fatigue as 'the state of an organism's muscles, viscera, or CNS, in which prior physical activity and/or mental processing, in the absence of sufficient rest, results in insufficient cellular capacity or system wide energy to maintain the original levels of activity and/or processing by using normal resources'. In other words, fatigue is characterised by a reduction in available resources and a decreased ability to continue task performance at one's highest potential as a result of engagement in either mental or physical tasks for a period of time without adequate rest.

In this thesis, the term 'fatigue' will be used in cases where this term is stated by the authors of the respective work. However, given the range of complexities associated with the term, the difficulty in setting definite observable criteria and the ambiguity around the definition of fatigue, the term 'exercise-intensity' will be adopted in this research. According to Winter (2006) the expression ''intensity of exercise'' should be used to describe exercise challenges and can be used universally, irrespective of the form of exercise. The adoption of the term means that physiological effects of exercise can be examined from a firmer scientific base (Winter, 2006). This term more accurately reflects the nature of the field-based exercise protocols that form the basis of the studies conducted within this program of research. These protocols are more appropriate and relevant to sports performance, especially when compared to the more circumscribed and artificial forms of exercise used extensively in past work relating to this topic (Jones, 1999).

1.3 Fatigue effects on performance – a complex issue

Fatigue presents a complex problem for research (Holding, 1983). Despite decades of considerable research, the etiologies of muscle fatigue have yet to be clearly established (Fitts, 1994). It is now widely regarded that multiple factors are clearly involved; the relative importance of each is dependent on the fibre type composition of the contracting muscle(s), the intensity, type, and duration of the contractile activity and the individual's degree of fitness. It is also clear that the cause of fatigue is complex, influenced by events in both the periphery and the CNS (Meeusen, Watson & Dvorak, 2006). Historically, the potential factors involved in fatigue development fall into two broad categories (Giannesini, Cozzone & Bendahan, 2003). Central factors are those which cause fatigue by disturbing neuromuscular transmission between the central nervous system and muscle membrane, while peripheral factors, lead to alterations within the muscle itself (Westerblad et al., 1991; Fitts, 1994). The relative contributions of central and peripheral factors in the development of fatigue, however, has been subject to controversy for many decades (Giannesini, Cozzone & Bendahan, 2003).

McKenna (2003) defines peripheral muscle fatigue as any fatigue arising from the failure of mechanisms at or beyond the neuromuscular junction. Central fatigue is defined as any fatigue originating before this point in the neural pathways responsible for activation of muscle (Bigland-Ritchie, 1981). Peripheral mechanisms of fatigue have been extensively studied and include impairments in neuromuscular transmission, impulse dysfunction, dysfunction in calcium release and uptake, substrate depletion, as well as various other metabolic factors that disrupt energy provision and contraction. The detail of these impairments can be found in several very detailed reviews (Green 1987; Coggan & Coyle, 1991; Enoka & Stuart, 1992; Fitts & Metzger, 1988).

The idea that muscular activity might be limited by the CNS is deeply rooted in sports and lay thinking (Jones, 1999). Bisciotti (2002) also stresses that central factors cannot be overlooked when examining why fatigue develops in humans. James, Sacco and Jones (1995) point out that central fatigue may come about as a result of conscious or unconscious mechanisms. The participant may decide that the sensations are unacceptable and deliberately reduce the level of activity. Alternatively, afferent information from working muscles, joints or tendons may inhibit motor activity at spinal or supraspinal levels, leading to an obligatory loss of performance that no amount of voluntary effort can overcome. Kalmar and Cafarelli (2004) reinforce this latter point adding that with fatigue, central output to muscles may diminish as a result of a number of underlying physiological processes. However, in human participants it is currently not possible to measure changes at these sites directly (Kalmar & Cafarelli, 2004).

It is clear from the previous points that this topic is fraught with complexities. Green (1990) reinforces this, adding that the complexity of possibilities is overwhelming and isolation of a “weak link” or specific failing process may be fortuitous at best. Reilly (1997) cites that the occurrence of fatigue may be linked with a host of physiological factors. Åstrand et al. (2003), while acknowledging the complexity of physiological factors, also stress the importance of psychological factors. An important weakness in current thinking in exercise physiology according to Noakes (2000) is the fact that we lack certain knowledge of the precise factors that determine fatigue and hence limit performance. In part, this is because some scientists remain unaware that their research is based on the (subconscious) acceptance of one specific model of human exercise physiology (Noakes, 1997 & 1998). However, it is unlikely that one single physiological model adequately explains human exercise performance under all conditions.

Experimentally, trying to identify the factors underlying the effects of physical exercise or fatigue on performance has proved extremely difficult, even in stringently controlled environments. This was illustrated by Bangsbo (1994) who conducted a series of laboratory-based investigations attempting to identify intramuscular factors causing fatigue. The series of investigations failed to identify any single factor (e.g. hydrogen ions, lactic acid, potassium imbalance, ammonia, or energy depletion) or combination of factors that would explain the concept definitively. Lambert and Flynn (2002) make the point that it is difficult to determine the cause(s) of muscular fatigue during exercise because changes in substrates and/or metabolites believed to cause muscle fatigue are coincident with changes in other substrates or metabolites. For example, during intense contraction to fatigue there is a fall in muscle pH and an increase in ADP and inorganic phosphate. Identifying which of these is the causative factor is not easy. Another major obstacle in isolating the cause of fatigue to specific sites is the wide number of compensatory adjustments that may be invoked during sustained activity in order to minimise the impact of a failing process and to maximise work tolerance. Depending on the type of task and the specific criteria used, the potential strategies include altering rate of coding and recruitment within muscle and rotating between different synergist muscles. Potential strategies may also extend to different excitation and contraction processes within the muscle (Patla, 1987, as cited in Green, 1990).

Conflicting results in the scientific literature exploring the effects of exercise intensity on performance reflect large differences in the types of tasks used (motor, sensory, cognitive and response time) (Aks, 1998). Methodologies are also different in terms of criteria, type, duration and intensity of exercise as evidenced in Table 1. Conflicting results may also be due in part to the fact in some studies tasks were performed while exercising but after exercise in others (Tomporowski & Ellis, 1986; McMorris & Keen, 1994). In summary, it is well known that impairment of performance resulting from exercise or fatigue differs according to the types of contraction involved, the muscle groups tested and the exercise duration and intensity. Depending on these variables, strength loss can originate from several sites from the motor cortex through to the contractile elements. Central and peripheral fatigue hypotheses have been argued and counter-argued throughout the scientific literature. As the topic of fatigue is increasingly studied by muscle physiologists, neuroscientists and clinicians, it becomes more difficult to summarise the state of knowledge (Gandevia et al., 1995). The quest for mechanisms to explain fatigue therefore, will undoubtedly consume the efforts of scientists for many years to come.

1.4 Methods and criteria for measuring exercise intensity

To date, studies investigating the effects of exercise intensity / fatigue on performance have provided conflicting and often contradictory findings. Investigators have attributed the diversity of findings to poor and inconsistent experimental designs among other factors (Aks, 1998). Due to the lack of consistency, a valid comparison of previous research findings is often difficult (Anshel & Novak, 1989). One inconsistency in terms of experimental design is the diversity of methods and criteria used to measure or generate fatigue states. For example, in terms of modalities, arm, cycle and rowing ergometers, treadmills, stabilometers, step heights, isokinetic dynamometers, barbells and other resistance type equipment have all been used to generate the required exertion level or intensity. Table 1 provides a summary of some of the methods and criteria for setting exercise intensity from a selection of the more prominent studies in the scientific literature. This is by no means an exhaustive list and many unconventional methods have not been included. However, as can be seen from this table the most widely used modality to set exercise intensity is the cycle ergometer and the isokinetic dynamometer for inducing more localised fatigue states. Furthermore, researchers have used a wide variety of criteria for setting exercise intensity which are also summarised in Table 1. Some of these include target heart rates, percentage of VO_2 max, contractions to the point of volitional exhaustion or contractions at a percentage of maximal voluntary contraction (MVC), among others. The conflicting results throughout the literature relating to this topic may be due in part, to this wide variety of methods and criteria used.

The limitations of some of the initial methods include the fact that many researchers failed to set the exercise intensity based on the individual participant’s fitness level.

This point will be developed further in the subsequent section of this work. However, more recent researchers such as McMorris and colleagues have controlled for an individual’s fitness level. In their studies, McMorris and colleagues calculated a participant’s maximum power output (MPO) and then set the exercise intensity as a percentage of this MPO value. Similarly, rather than using target heart rates (common in Table 1) a more preferable method is using heart rate reserve (HRR). This calculation or formula was developed originally by Karvonen, Kentala, and Mustala (1957) and fundamentally factors in resting heart rate, an indicator of one’s fitness level. Therefore, this formula constitutes a more individualised method of setting exercise intensities. This method has been employed by researchers such as Szabo and Gauvin (1992) and Al-Nakeeb et al. (2003 & 2004). Previous researchers have also utilised RPE scales (Marshall, Kozar & Moore, 1992) to set exercise intensity. More recently, researchers such as Royal et al. (2006) and Al-Nakeeb and Lyons (2007) have chosen to use more than one criterion to establish the required intensity, combining for example, heart rate reserve with the equivalent rating of perceived exertion (RPE). In these studies, both criteria had to be met and then maintained for a further minute to reach the desired exercise intensity.

In some studies, the use of general exercise modes, as opposed to isolating the specific muscles used in the criterion task, is a methodological limitation (Anshel & Novak, 1989). It is hardly surprising therefore, that Welch (1969) found heavy muscular fatigue of the legs did not transfer and impair performance involving speed and accuracy of arm movements. Other researchers such as Spano and Burke (1976) and more recently, Went and El-Sayed (1994) examined the effect of work and exercise intensity respectively, on rotary pursuit. However, lower limb muscle groups were recruited in the exercise tasks while rotary pursuit performance is predominantly an upper-body movement task. In these studies, and other more recent work (McMorris et al., 2003), the muscle groups recruited in the exercise tasks were not the same as those being used in the performance task. Linked to the point by Anshel and Novak (1989), Arnett, DeLuccia and Gilmartin (2000) used an anaerobic fatiguing task in their study and their justification was that an anaerobic fatiguing task was more reflective of the fatigue experienced during games. Accordingly, they felt that this type of task was more appropriate than an aerobic test. Developing fatigue states from isolated forms of isometric, concentric or eccentric contractions is also problematic because in reality, exercise seldom involves a pure form of these types of isolated muscle actions (Komi, 2000). Furthermore, many previous investigations on this topic have used very circumscribed and artificial forms of exercise (Jones, 1999).

Recently, researchers have endeavoured to generate fatigue states through the utilisation of various energy sources. McMorris et al. (2000) for example, examined the effect of exercising at the adrenaline threshold and at maximum power output on decision-making. The use of electromyography has also been explored (Clarys, 2000; Devienne et al., 2000; Ogiso et al., 2002; Rodaki, Fowler & Bennett, 2002; Farina, Merletti & Enoka, 2004) in terms of setting criteria for fatigue. More recently, authors such as Royal et al. (2006), Gabbett (2008) and Vesterinen et al. (2009) have attempted to develop exercise / fatigue states using sport-specific movements and actions so as to ensure that the protocols employed are as ecologically valid as possible.

Table 1. Summary of commonly used modes and protocols to set exercise intensity

Author(s)	**Modality**	**Exercise Protocol**
Schmidt (1969)	Cycle ergometer	Workloads of 750kgm/min & 1200kgm/min
Carron (1972)	Cycle ergometer	Heart rate of 180bpm
Williams & Singer (1975)	Cycle ergometer	Heart rates of 100-110, 135-145 & 165-175bpm
Spano & Burke (1976)	Cycle ergometer	60%, 75% & 90% HRmax
Vlahov (1977)	Cycle ergometer	Heart rates of 100, 125, 150 & 175bpm
Evans & Reilly (1980)	Cycle ergometer	Heart rates of 100, 125, 150 & 175bpm
Salmela & Ndoye (1986)	Cycle ergometer	VO_2 max test to exhaustion
Allard et al. (1989)	Cycle ergometer	60% of PWC 170 test performance
Anshel & Novak (1989)	Cycle ergometer	45%, 60% & 75% VO_2 max
Szabo & Gauvin (1992)	Cycle ergometer	40% & 60% heart rate reserve
Hoffman et al. (1992)	Cycle ergometer	Heart rates of 130, 150, 170bpm & exhaustion
Coté, Salmela & Papathanasopoulu (1992)	Cycle ergometer	Heart rates of 115, 145, 160 & 180bpm.
Went & El-Sayed (1994)	Cycle ergometer	25%, 40% & 85% VO_2 max

(Table 1 continued)

Delignières, Brisswalter & Legros (1994)	Cycle ergometer	20%, 40%, 60% & 80% VO_2 max
McMorris & Keen (1994)	Cycle ergometer	70% & 100% MPO
McMorris et al. (1994)	Cycle ergometer	70% & 100% MPO
Hogervorst et al. (1996)	Cycle ergometer	75% MPO
McMorris & Graydon (1996a) & (1996b)	Cycle ergometer	70% & 100% MPO
McMorris & Graydon (1997a) & (1997b)	Cycle ergometer	70% & 100% MPO
Féry et al. (1997)	Cycle ergometer	30%, 60% & 90% VO_2 max
Aks (1998)	Cycle ergometer	147 & 294 watts (males) 93 & 186 watts (females)
McMorris et al. (1999)	Cycle ergometer	Incremental test to adrenaline threshold & MPO
Arnett, DeLuccia & Gilmartin (2000)	Cycle ergometer	70% of mean power output (during wingate test)
McMorris et al. (2000)	Cycle ergometer	Incremental test to adrenaline threshold & MPO
Yaggie & Armstrong (2004)	Cycle ergometer	Serial Wingate tests
McMorris et al. (2005)	Cycle ergometer	70% & 100% MPO
Lemmink & Visscher (2005)	Cycle ergometer	Workrate of 4 watts per kilogram of body mass)
Al-Nakeeb & Lyons (2007)	Cycle ergometer	50% & 80% HRR & RPE
Thomas et al. (1975)	Treadmill	Heart rates of 175-180bpm maintained for 2 minutes
Hancock & McNaughton (1986)	Treadmill	Incremental test to anaerobic threshold
Legros et al. (1992)	Treadmill	95% &125% of VO_2 max
Al-Nakeeb et al. (2003)	Treadmill	90% HRR
Sharpe & Miles (1993)	Isokinetic dynamometer	5 X 20 second isometric MVC's
Marks & Quinney (1993)	Isokinetic dynamometer	Maximal isokinetic quadriceps contractions to exhaustion
Johnston et al. (1998)	Isokinetic dynamometer	Volitional exhaustion (leg flexion/extensions at 50% MVC
Pedersen et al. (1999)	Isokinetic dynamometer	Volitional exhaustion (shoulder flexion / extensions at 10% MVC)
Forestier, Teasdale & Nougier (2002)	Isokinetic dynamometer	Isometric test - 70% of MVC for 40 seconds
Rodacki, Fowler & Bennett (2002)	Isokinetic dynamometer	Loaded leg extensions (50% body mass) until volitional exhaustion
Apriantono et al. (2006)	Isokinetic dynamometer	Loaded knee flexion /extensions (50% body mass) until volitional exhaustion
Francisco et al. (2007)	Isokinetic dynamometer	30 max concentric repetitions at an angular velocity of 120^o/sec.
Venancio et al. (2007)	Isokinetic dynamometer	30 max concentric/eccentric repetitions at an angular velocity of 180^o/sec.

(Table 1 continued)

Meyers et al. (1969)	Step height	Harvard step test
Vlahov (1977)	Step height	Harvard step test
Lees & Davies (1988)	Step height	Stepping at a cadence of 30 steps/min for 6 minutes
Sparrow & Wright (1993)	Step height	47, 75 &120 watts
Waldron & Anton (1995)	Step height	Harvard step test
Godwin & Schmidt (1979)	Arm ergometer	2min serial fatigue bouts until exhaustion
Evans et al. (2003)	Arm ergometer	70% VO_2peak
Al-Nakeeb et al. (2002 & 2003)	Arm ergometer	90% HRR
Al-Nakeeb, Lyons & Nevill (2004)	Arm ergometer	90% HRR
Smilios (1998)	Leg press weights station	Loads of 50%, 70% & 90% of 1-RM until volitional exhaustion
Berger & Smith-Hale (1991)	Leg press weights station	Loads of 60% & 80% 1RM until volitional exhaustion
Marshall, Kozar & Moore (1992)	Leg extension bench	Weighted leg flexion / extensions until 'hard' level on the Borg (1982) scale
Cotton et al. (1974)	Barbell weight	Curling 23lb barbell at 30rpm for 5 minutes
Al-Nakeeb et al. (2005)	Rowing Ergometer	70% and 90% HRR & RPE
Rodacki, Fowler & Bennett (2001)	Force Platform	Maximal continuous jumps until jump height dropped to 70% of resting jump height

PWC – Physical work capacity

1RM – One repetition maximum

VO_2 max – Maximal oxygen consumption

RPE – Ratings of perceived exertion

HRmax – Maximum heart rate

MPO – Maximal power output

HRR – Heart rate reserve

The methods employed to develop moderate and intense exercise conditions in this work embrace many of the points raised here and consider the limitations highlighted by researchers past and present. The justification for the methods employed in the experimental studies conducted as part of this work is highlighted in the individual chapters associated with those studies.

1.5 Consideration of individual fitness levels

Regardless of the type of fatiguing task chosen, a perusal of the literature concerning the effects of exercise or fatigue on motor performance indicates that researchers have not controlled for such intervening variables as the participant’s fitness level (Anshel & Novak, 1989). This is a fundamental limitation indeed, as not all humans are physiologically equal. While a calculated/standardised degree of physiological strain may be tolerable for the majority of participants, it could constitute an intolerable strain for others (Ainslie et al., 2006). Individuals also recover at differing rates and so a more appropriate design may involve investigating the effects of exercise during a quantifiable state for example, at varying percentages of heart rate max or VO_2 max.

McMorris and Graydon (1996b) argue that previous research into the effect of exercise on cognitive performance has been confounded by poor experimental designs, a claim reinforced by Aks (1998). More specifically, they claimed that a critical limitation of some research studies was the failure to take into account individual differences in fitness levels. Brisswalter, Collardeau and René (2002) add that the failure to control for physical fitness is one of the reasons underpinning the wide diversity of experimental results found in the literature. Consequently, the use of an individual relative workload is recommended (Davranche & Audiffren, 2004). Even though Tomporowski and Ellis (1986) identified these limitations, not all studies have accounted for the fitness levels of the individual participants. Many studies for example, had participants stepping at the same rate regardless of fitness level (Lees & Davies, 1988; Sparrow & Wright, 1993), exercising at the same heart rate (Hoffman et al., 1992; Coté, Salmela & Papathanasopoulu, 1992), or work rate (Aks, 1998). Further examples can be seen in Table 1. In some research studies, participants simply performed the Harvard step test (Meyers et al., 1969; Vlahov, 1977; Waldron & Anton, 1995). The majority of researchers today are considering this in their experimental design. Lemmink and Visscher (2005) for example, set the workloads relative to the participant's body mass. This ensures that exercise intensities are equal and consistent across participants and relative to the fitness level of the participant. McGlynn, Loughlin and Rowe (1979) used a specific target heart rate to define exercise intensity but used the Karvonen method to calculate target heart rate reserve. As already mentioned, this calculation takes into account the participant's resting heart rate which is one of a number of indicators of individual fitness level.

1.6 Exercise and arousal

A considerable amount of research has been undertaken into the effects of exercise on performance, some of which will be reviewed in subsequent sections of this work. While many studies in the 1960's took a non-theoretical stance (McAdam & Wang, 1967; Gutin & Di Gennaro, 1968a,b; Meyers et al., 1969), the first paper to present a theoretical rationale was Davey (1973) who argued that as exercise intensity increased, so did arousal. Although Davey (1973) made this claim, he did not explain why this should be the case. McMorris and Keen (1994) disagreed with this assumption however. They stated that, when physiological changes are the result of exercise, they are induced and mediated by the activated musculature and are responding to exercise load, i.e., attempting to maintain homeostasis. Somatic arousal rising from emotions, however, is induced by the CNS/brain and destroys homeostasis (McMorris & Keen, 1994). The basis of McMorris and Keen's argument was that during maximal intensity exercise, the individual is still in a state of homeostasis because they are able to maintain the required power output. Their heart rate and catecholamine responses are needed in order to continue exercising. However, a person in a resting condition or carrying out normal day to day activities and who is highly aroused due to emotions, is no longer in a state of homeostasis. Their heart rate and catecholamines responses exceed that required for maintaining their physical activity level.

Cooper (1973) did attempt to account for an exercise-arousal interaction, stating that exercise induces physiological and biochemical changes that are similar to those found when arousal increases due to emotional stress. He pointed out that during exercise there are increases in heart rate, respiratory rate, blood pressure and sweating. Many authors (Lacey & Lacey, 1970; Sothman, Hart & Horn, 1991; Chmura, Nazar & Kaciuba-Uścilko, 1994; McMorris & Graydon, 1996b) also claimed that exercise induces increases in CNS levels of catecholamines, adrenaline, and noradrenaline which are thought to be indicative of increases in arousal. The physiological changes that take place when people exercise are also seen when an individual's arousal levels rise (McMorris & Graydon, 1996b). More recently, Royal et al. (2006) supported the notion that as exercise intensity increases, arousal increases too. However, some authors have urged caution here (McMorris et al., 1999; Brisswalter, Collardeau & René, 2002). McMorris et al. (1999) argued that it is not clear how physiologic changes would increase arousal in the CNS and that this relationship needs to be explained better than simply pointing to similarities in the physiologic symptoms shown by both types of arousal. In the literature an increase in arousal, induced by exercise intensity has been linked to increased heart rate and/or an increase in the level of perceived exertion (Brisswalter, Collardeau & René, 2002). The rationale behind this observation is that physiological changes from exercise are described as increases in arousal. However, as alluded to already, the relationship between arousal and exercise is still not fully understood.

Arousal is a non-unitary concept and there are complex interactions between arousal and several multidimensional psychological concepts such as motivation and attention. Research by Ursin (1988) suggested that increases in arousal are not identical to changes in heart rate, galvanic skin responses, plasma cortisol, growth hormone, or increases in metabolism (Ursin 1988, as cited in Zaichkowsky & Baltzell, 2001). Each of these physiological changes constitutes only part of the arousal response. Today, the majority of researchers conceptualise arousal as a complex, multidimensional construct including a physiological dimension paired/grouped with a cognitive, affective, and/or behavioural dimension (Zaichkowsky & Baltzell, 2001). Gould and Udry (1994) expand on this multidimensional explanation of arousal, stating that it is a mistake to conceptualise arousal as a unitary construct. Instead, arousal should be viewed as a multidimensional construct that contains a physiological arousal component and a cognitive interpretation-appraisal component.

Sanders (1983) argued while physiological reactions to stress may be very similar, performance changes may be different for different stressors. It is possible that, while exercise induces physiological and biochemical changes which are similar to those induced by arousal, the effect may not be entirely synonymous. Dietrich & Audiffren (2011) in their analysis of the links between exercise, arousal, central catecholamines and improvements in cognitive performance reverted back to the idea that exercise is an arousing stressor. However, they supported their claim by citing the following set of findings from animal and human research: (1) synthesis of noradrenaline increases in the rat brain during strenuous and prolonged exercise; (2) concentration of plasma catecholamines increases during exercise; (3) brain noradrenergic activity increases during cortical activation; (4) the level of cortical arousal is related to the level of activity in the locus coeruleus; and (5) exercise can increase the activation of the reticular formation via somatosensory feedback provided from limb movements.

Even today the arousing effects of exercise, on peripheral and central systems, are well documented (Dietrich & Audiffren, 2011). Acute exercise activates both the sympathetic nervous system and the hypothalamo–pituitary–adrenal axis, which results in the release of catecholamines and indolamines, both centrally and peripherally (Meeusen and De Meirleir, 1995; Wittert, 2000). The idea that physical exercise is an arousing stressor (Cooper, 1973; Davey, 1973) however is still being pursued in recent research (Draper, McMorris & Parker, 2010; Higashiura et al., 2009; Kashihara et al., 2009) pertaining to the effects of exercise on cognitive function specifically. A recent review paper (Lambourne & Tomporowski, 2010) pertaining to the effects of exercise on cognition refers consistently to ‘exercise-induced arousal’. The relationship between exercise and arousal needs better explanation however, and this needs to be underpinned by sound scientific research and enquiry. Until such time, research examining exercise or fatigue effects on performance of gross-motor, sport-specific and cognitive tasks will continue to attempt to explain their findings in terms of one of the numerous theories of arousal. These theories of arousal have attempted to explain the arousal-performance relationship. These models have been argued and counter-argued; yet to date, not one has decisively explained or conclusively predicted this relationship (Zaichkowsky & Baltzell, 2001). The most prominent theories of arousal will be reviewed next.

1.6.1 Yerkes & Dodson's (1908) inverted-U theory

One of the earliest theories of arousal is that of the inverted-U theory, which was proposed by Yerkes and Dodson (1908). According to their theory, when arousal is low, performance will be poor. As arousal rises to a moderate-intensity, performance will reach an optimal level, the top of the inverted-U. If arousal continues to rise, performance will begin to deteriorate until it eventually returns to a level equal to that shown during low levels of arousal (Figure 1).

Figure 1. Yerkes & Dodson's hypothetical relationship between arousal level and performance. Taken from McMorris (2004)

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Yerkes and Dodson's (1908) inverted-U theory has received much support from other prominent researchers since then (e.g. Tomporowski & Ellis, 1986) and continues to be referred to in studies of this nature (McMorris et al., 1994; Waldron & Anton, 1995; McMorris et al., 2000). Tomporowski and Ellis (1986) argued that the inverted-U effect could be explained by Easterbrook's (1959) cue utilisation theory which will be subsequently examined here.

1.6.2 Inverted-U theory and Easterbrook's (1959) cue utilisation theory

Many authors have drawn on Easterbrook's (1959) development of Yerkes and Dodson's (1908) theory as the theoretical basis underpinning their research (Isaacs & Pohlman, 1991; McMorris & Keen, 1994; McMorris & Graydon, 1996b). Easterbrook's (1959) theory has the advantage over Yerkes and Dodson's (1908) theory in that it provides an explanation for the changes in performance. Easterbrook's theory suggested that variations in arousal will produce a change in attentional processes. Accordingly, when arousal is low, attention is focused on both relevant and irrelevant cues and thus, performance remains poor. However, as arousal rises to a moderate level (top of the inverted-U) attention narrows onto task-relevant cues only and performance becomes optimal. If arousal continues to rise to a high level, attention will narrow further and even relevant cues will be missed; therefore, performance returns to baseline or low arousal levels. A similar account is offered by Nideffer's (1979) attention control theory. A number of research studies support inverted-U (Davey, 1973; Reilly & Smith, 1986; Salmela & Ndoye, 1986; McMorris et al. 1994) but not necessarily attention narrowing (Coté, Salmela & Papathanasoupou, 1992). More recently, research by Lemmink and Visscher (2005) has provided some support for attentional narrowing. They also emphasised that in order for attention narrowing to occur, the participant must be highly aroused. If the participant is not, then the over-narrowing effect will not be evident. Research exploring the effect of exercise on cognitive performance more specifically, has failed to unequivocally support the inverted-U hypothesis. This lack of support according to Tomporowski and Ellis (1986) is due to poor experimental designs such as failing to take into account individual differences in fitness levels. However, this explanation alone is not sufficient as researchers (e.g. McMorris et al., 2005) have since accounted for individual differences in fitness levels and still failed to show an inverted-U effect.

It should also be stated that the inverted-U hypothesis is not an entirely true reflection of the claims of Yerkes and Dodson (1908). Yerkes and Dodson also stated that the type of task would affect the arousal-performance interaction. This view was later supported by Oxendine (1984). Yerkes and Dodson (1908) also claimed that if a task was complex, moderate levels of arousal would result in optimal performance, while high levels would cause a deterioration in performance. However, if the task was simple then it would require high levels of arousal for optimal performance to be exhibited. Zaichkowsky and Baltzell (2001) point out that the challenge for researchers is testing this hypothesis in the motor domain. In addition to the problem of defining high and low arousal, there is the problem of defining simple and complex tasks. Billing (1980), however, offered one such approach suggesting that task complexity should be based on information processing demands and complexity of the motor response. Using this classification, according to Zaichkowsky and Baltzell (2001) it can be inferred that motor tasks requiring concentration, judgment, discrimination and fine motor control are best performed under low or moderate states of arousal. In contrast, motor tasks requiring strength, endurance, speed or ballistic movements require higher levels of arousal. An overview of Billing's (1980) taxonomy is provided in section 1.6.6.

Although related to individual differences and skill level, attentional processes deserve special consideration as a factor mediating arousal and performance. Several writers have suggested that attention and cue utilisation may be the crucial factor in understanding anxiety/arousal and performance. Easterbrook's (1959) cue utilisation theory was one of the first theories of arousal and performance but does not have universal support in the literature and since then many other theories have emerged.

1.6.3 Drive theory

Drive theory was derived from the learning theory work of Hull (1943) and was later modified by Spence and Spence (1966). This theory predicts that performance (P) is a multiplicative function of habit (H), drive (D) and incentive value (I). Expressed as an equation it could be expressed as P = H x D X I. The construct of habit here refers to the dominance of the correct or incorrect response. Increases in arousal should enhance the probability of making the dominant response. When performance errors are frequently made, as may be the case with novices or in the early stages of skill acquisition, the dominant responses are more likely to be incorrect. Conversely, when performance errors are infrequent, as may be the case with expert performers, the dominant response is typically correct.

Hull (1943) saw drive as physiological arousal, habit as the dominance of correct or incorrect responses and incentive as how important the activity is to the performer. With respect to arousal effects on performance therefore, high levels of arousal do not always result in poor performance although sometimes this is the case. Furthermore, moderate levels of arousal do not always result in better performances as hypothesised in the inverted-U theory. Instead, there is a positive relationship between arousal and performance when a task is well-learned (Hull, 1943). This is illustrated in Figure 2.

Figure 2. Hull's hypothetical relationship between arousal level and performance of well-learned tasks. Taken from McMorris (2004)

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Linear relationships exist for gross motor activities involving strength and speed. These types of activities are typically well-learned, with strongly formed habit patterns. Therefore, a high level of arousal would be desirable for optimal performance in these types of gross motor skills (Oxendine, 1984). With respect to tasks that are not well-learned however, increases in arousal will either have no effect on performance or lead to a deterioration in performance (Hull, 1943). This is illustrated in Figure 3.

Figure 3. Hull's hypothetical relationship between arousal level and performance of tasks that are not well-learned. Taken from McMorris (2004)

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After an extensive review of the literature, Martens (1971) concluded that drive theory may not provide an adequate explanation of the relationship between arousal and performance in sport. Zaichkowsky and Baltzell (2001) also put forward that drive theory is difficult to test in the area of motor performance due to the need to determine habit strength (i.e. dominance of the correct or incorrect responses). This is particularly difficult for complex motor skills. Despite this, studies exploring the effects of exercise intensity or fatigue on performance have found results consistent with the postulates of Hull (1943) for well-learned tasks (e.g. Delignières, Brisswalter & Legros, 1994; McMorris & Keen, 1994; Marriott, Reilly & Miles, 1993) and tasks that are not well-learned (Al-Nakeeb et al., 2005 & 2007; Berger & Smith-Hale, 1991; Evans & Reilly, 1980). Therefore, while anecdotal reports from athletes and other performers suggest that excessive arousal disrupts performance (Zaichkowsky & Baltzell, 2001) further research is warranted exploring the predictions here.

1.6.4 Kahneman's (1973) multidimensional allocation of resources theory

None of the theories examined thus far have unequivocal support in the scientific literature. This is due in part to major methodological problems affecting previous studies examining the relationship between arousal and performance. One such issue however, is the unidimensionality of this relationship. Unidimensional theories such as those described above have been criticised as being too simplistic (Humphreys & Revelle, 1984; Kahneman, 1973; Pribram & McGuinness, 1975; Sanders, 1983). As a result, more recent researchers (Delignières, Brisswalter & Legros, 1994; McMorris & Graydon, 1996a, 1996b, 1997a, 1997b; Royal et al., 2006) have drawn on multidimensional theories as the theoretical rationale for their hypotheses.

The first of these theories was put forward by Kahneman (1973) who introduced the notion that performance is affected by arousal and what he termed cognitive effort. Arousal refers to the amount of resources available to the CNS, whereas effort is responsible for the allocation of these resources. According to Kahneman, arousal is the physiological and biochemical response to stress and results in increases in CNS resource levels, which he called allocatable resources. In other words, as arousal rises there are more resources available to the individual. The key issue however, is how these resources are allocated; this is the role of cognitive effort. Kahneman claimed that even at low levels of arousal, it is possible for cognitive effort to allocate resources to task-specific information and so ensure that performance does not suffer. He stated that at high levels of arousal, it was impossible for effort to totally overcome the negative effects of arousal sufficiently to ensure optimal allocation of resources. According to Kahneman therefore, performance when arousal is high will be less than optimal as cognitive effort cannot focus attention solely on task-relevant information.

In their processing-efficiency theory, Eysenck and Calvo (1992) distinguish between performance effectiveness, which refers to the quality of task performance, and processing efficiency, which refers to the product of performance effectiveness divided by effort. Effort is determined by the amount of processing resources invested in the task. The quantification of ‘effort’ however, remains a major stumbling block (Graydon, 2002). Simply stated, processing efficiency theory holds that, when confronted with anxiety-inducing circumstances, the efficiency by which information is processed and acted upon decreases, potentially rsulting in performance decrements (Janelle, 2002). Therefore, while performance may remain similar in high-anxiety compared to low-anxiety circumstances, the individual is required to work harder in the high-anxiety conditions to maintain performance. In this case, while performance effectiveness is being maintained, performance efficiency is impaired. In some cases, performance may actually improve when one is anxious due to the motivational aspects of anxiety that allocate additional resources for task performance. Linked to this idea, Eysenck (1992) claimed that if a task is well learned, highly motivated performers can allocate sufficient resources to ensure optimal performance even at high levels of arousal. This is similar to drive theory (Hull, 1943). Sufficient resources are allocated to the task therefore, to ensure optimal performance. Other researchers have supported this view, adding that at low levels of arousal, motivated individuals could also allocate what resources were available to task-relevant cues and overcome the restricted availability of allocatable resources (Humphreys & Revelle, 1984). Consistent with Kahneman’s (1973) notion that attentional capacity is limited processing-efficiency theory also assumes a capacity notion of attention.

1.6.5 Nideffer’s (1979) test of attentional and interpersonal style

Although Nideffer’s test has been given under different sport conditions (Nideffer 1990, Summers & Ford, 1990), few researchers have examined one of the basic assumptions of Nideffer’s model, namely that physical arousal associated with exercise, leads to narrowing of attentional focus. Although attentional narrowing with stress is a basic assumption of the Nideffer model (1979), it has not yet been empirically validated with exercise as a stressor (Tomporowski & Ellis, 1986).

Attentional narrowing is not just a central component of Nideffer’s model, it is also fundamental to most of the theories of arousal reviewed here. Tomporowski and Ellis (1986) for example, put forward the idea that physical discomfort resulting from fatiguing exercise may result in performers focusing on their perceptions of pain rather than attending to the performance cues. Easterbrook (1959) hypothesised that as a result of this, task relevant information was missed. Schmidt and Lee (1999) point out that in addition to the reduced range of cues that can be attended to as arousal increases, there is an increase in the number of shifts in attention to different input sources. Researchers such as Kahneman (1973) referred to this effect as increased distractibility. It is possible therefore, that when exercise is fatiguing, attention is inhibited. Furthermore, with respect to the effects of exercise on attention, Salmela and Ndoye (1986) highlight that when participants reach high-intensity exercise there is often an internalising of attention as the participant focuses on the internal signals of pain and fatigue rather than upon the external stimuli. Newsholme, Ackworth and Blomstrad (1987) expand on this notion, adding that prolonged exercise more specifically, results in an increase in brain serotonergetic activity which may augment lethargy, cause an altered sensation of effort, perhaps a differing tolerance of pain/discomfort, and a loss of drive and motivation, thus limiting physical and mental performance.

1.6.6 Arousal theories and task complexity

It is clear from the various theories explored here that in many instances the type of task as well as the complexity of the task affect the arousal-performance relationship. Yerkes and Dodson for example, later supported by Oxendine (1984) stated that if a task was complex, moderate levels of arousal would result in optimal performance, while high levels would cause a deterioration in performance. However, if the task was simple then it would require high levels of arousal for optimal performance to be exhibited. The complexity of the task is also a key consideration in the work of Hull (1943), Eysenck and Calvo (1992) and Kahneman (1973). In light of this, it is important identify how task complexity will be classified in this program of research.

Billing (1980) put forward that regardless of the particular terminology used, past authors agree on the importance of perceptual awareness of the act/skill to be performed, a decision as to how to act, the production of the motor act, and the necessity of feedback information. Since these four major components comprise each motor performance, the difficulty of skills can be identified by examining the complexity of each of these components, with total complexity being the combination of all four.

Although the motor act is the most obvious means of rating the difficulty of a performance, it is only one parameter upon which complexity depends. Attention to the other three phases of the motor performance is essential to the determination of total complexity (Billing, 1980). In the context of this research, Billing's taxonomy is particularly pertinent as the skills being examined are all gross-motor tasks, sports-related but the perceptual and decisional aspects vary as the research develops. Consequently, Billing's (1980) taxonomy enables each skill to be analysed in terms of its complexity according to the following suggested components of a motor performance; (1) perceptual complexity, (2) decision-making complexity, (3) motor act complexity and (4) feedback complexity.

With respect to the perceptual requirements of a task these can vary in complexity due to; (1) the number of stimuli which must be attended to, (2) the number of stimuli present, (3) the speed or duration of the stimuli, (4) the intensity of the stimuli and (5) the extent to which stimuli are conflicting or confusing. Therefore, if a large number of stimuli must be attended to or the number of stimuli available are less than optimal, task complexity is increased. If important stimuli are available only for a short duration, task difficulty increases. If the intensity of the important stimuli are marginal, as happens when vision is impaired, the activity becomes more difficult. Finally, if conflicting stimuli are present which create confusion, as in the case of 'faking' movement, complexity again increases. Thus, it is possible to attribute a portion of the difficulty of any task directly to the perceptual requirements or the conditions present. Alteration of these will either increase or decrease the total task complexity.

With respect to the decision making requirements of a task again the complexity can be increased by manipulation of 5 main factors; (1) increasing the number of decisions necessary, (2) increasing the number of alternatives per decision, (3) increasing the speed of decision making, (4) sequencing of the decisions and (5) increasing the number of items needed from memory. With respect to the latter point here, if one decision effects the alternatives available in later decisions or if extensive memory comparisons must be made, then the complexity increases. The items contributing to decision making complexity again can be manipulated to increase [or reduce] the difficulty of the performance task.

Motor complexity is the most obvious means of distinguishing between simple and complex skills or tasks (Billing, 1980). Again Billing (1980) set out 4 key factors that can be manipulated or changed in an effort to increase the complexity of the motor act:

(1) The greater the number of separate muscle actions producing either movements or stabilisation of the joints, the greater the difficulty of the motor act;
(2) Increasing the degrees of coordination of the actions;
(3) Increasing the speed and accuracy requirements that contribute to task difficulty;
(4) Increasing the precision required in a task by utilising smaller targets or increasing the passing distances.

The last facet according to Billing (1980) is that of feedback but this is less important in the context of the present work as feedback was only provided during familiarisation trials. A final key point regarding Billing's (1980) taxonomy is that while the four components (perceptual, decision, motor act and feedback) can vary in their complexity, they are not independent of one another. Perceptual input is the basis for decision making, the decisions are the basis for action, and the action produces feedback. However, a task could be quite complex in both perceptual and decision making but require only a very simple motor response. The complexity of any motor performance may be systematically increased by adjusting the complexity of any component therefore (Billing, 1980). This allows researchers with great flexibility to increase or decrease task complexity to suit the needs of the particular experimental study. This identification can be utilised to structure research hypotheses, develop drill progressions, identify problems in performances or adjust activities for differing groups/populations (Billing, 1980). It is for these reasons and the flexibility of this taxonomy that it was chosen for the purposes of this program of research.

1.7 Sports-related performance - motivation and pain tolerance

It is clear from the work presented thus far that the effects of exercise / fatigue on performance vary according to the type of task, the nature of the fatiguing task as well as the intensity of fatigue. Human performance under fatigue conditions is also influenced by many variables, not least those involving the psyche (Noakes, 2000). It is likely that there are a host of personality and psychological factors that influence performance under intense exercise or fatigue conditions.

One psychological variable that warrants attention is that of motivation. In some of the studies reviewed so far fatigue impacted negatively on performance, but in others there was no effect on performance, even under intense exercise or fatigue conditions. Tomporowski and Ellis (1986) suggested that well-trained individuals in particular, could compensate for the negative effects observed when fatigued even in extremely fatiguing conditions. The fatigue effect could be modified, for example, by incentive variables such as an individual's motivation. Early investigations related to this have been conducted by Isaac Ash who, in 1914, demonstrated that the point at which participants find it impossible to continue movements on a finger ergograph occurs well before muscular contraction becomes physiologically impossible. Thus, when participants were made to believe that the weight on their finger had been reduced, they found themselves able to begin the contractions again. Schwab (1953) had participants attempt to hang from a parallel bar for as long as possible under different incentive conditions. Those who were promised a five dollar reward were able to hang on for almost twice as long as controls or participants who were encouraged by the experimenter throughout the test. Taken together, both studies here illustrated that the final limit to performance may be set by central rather than peripheral factors. Other subsequent studies emphasised the importance of motivation and pain tolerance. Caldwell and Lyddan (1971) for example, examined fatigue effects on performance, stressing that the first limit encountered during physical exertion seems most often to be a psychological boundary rather than a physiological one.

The influence of fatigue on performance according to Mousseau (2004) has the potential to be moderated by an individual's motivation and/or ability to exert the additional effort required for task maintenance. With respect to long distance running, the ability to activate a muscle during high force contractions is attributed to peripheral events (Bigland-Ritchie et al., 1995). However, the greater willingness of subjects to put up with discomfort and push themselves harder is also fundamental. This willingness is clearly enhanced if the event takes place in a competitive environment. Hence, sports records are beaten more frequently in competitions in which the participants make a greater effort to get "psyched up" (Bigland-Ritchie et al., 1995). In 100m sprinting as an example, athletes often make an effort to get "psyched up" prior to the race. In the 2008 Summer Olympics final as an example, a new world record was set by the winner, five of the finalists ran personal best times with national records also achieved. Finally, it is also well known that pain or fatigue can be quickly forgotten in a state of emergency or an excess of enthusiasm (Holding, 1983). Taken together, these points illustrate that the psyche of the individual is clearly very important in sport.

The importance of motivation or tolerance of pain/discomfort has been noted by many other authors. In attempting to explain the importance of both motivation and pain tolerance, Newsholme, Ackworth and Blomstrad (1987) identified that during prolonged exercise specifically, there was an increase in brain serotonergetic activity. Increased brain serotonergetic activity may augment lethargy, cause an altered sensation of effort, perhaps a differing tolerance of pain/discomfort, and a loss of drive and motivation, thus limiting both physical and mental performance. However, the findings by Delignières, Brisswalter and Legros (1994) are very much contrary to this view. They found that experts specifically, exerted additional effort to overcome the effects of fatigue when challenged. Therefore, as performance increased, exertion also increased. Hogervorst et al. (1996) explain that an unconscious decision made by a participant to invest more effort in certain tasks is influenced by motivation and probably the effects of expectancy and so this may underpin the findings of their study.

Related to the idea of investing more effort, Brisswalter, Collardeau and René (2002) emphasise the role of resource allocation in terms of explaining the improvement in cognitive performance, specifically during exercise. According to Kahneman (1973) attentional resource capacity is variable and related to an estimation of task requirements. Therefore, the more attractive the task is perceived, the more the individual releases in that task-processing capacity. This hypothesis is in agreement with Tomporowski and Ellis (1986) who state that if the cognitive task is without challenge for an individual and does not require enough attentional resources, no exercise effect is observed. These latter conclusions indicated the importance of motivational factors in the relationship between exercise and cognitive processes.

In a broader context, motivation alters with exercise and may directly or indirectly change exercise performance (Heyes, Garnett & Coates, 1985; Chaouloff, 1991). During exercise, changes occur at all steps in force production from upstream of the motor cortex to the motoneuron, and peripherally from the muscle mitochondria to the myofibril. It would be surprising and biologically unsound if force production always failed because of impairment at one step in this process. Noakes (2000) reiterates this latter point emphasising that it would be very surprising if one single physiological model adequately explains human exercise performance under all conditions. Thus, human performance is unlikely to be adequately defined by any of these unitary models that are often presented as if they are mutually exclusive. Evolutionary design dictates multiple steps will tend to fail together but ultimately it is the CNS which may decide when enough is enough (Gandevia, Allen & McKenzie, 1995).

It has already been identified in this work that the relationship between arousal and exercise remains unclear. Arousal is a non-unitary concept and there are complex interactions between arousal and several multidimensional psychological concepts, such as motivation and attention. Szabo and Gauvin (1992) for example, suggest that researchers should examine experimentally how different levels of motivation and fitness in conjunction with varying exercise intensities and durations may affect cognitive performance. Other researchers (Arnett, DeLuccia & Gilmartin, 2000) have identified the importance of motivation and pain but have stated openly that their study had not manipulated these variables. Arnett, DeLuccia and Gilmartin (2000) concluded that the findings of their investigation must be interpreted with this latter point in mind. It is clear therefore, that issues regarding the psyche, motivation, and other personality factors/traits need consideration in research of this nature.

1.8 Research on the effects of exercise intensity on performance

A plethora of studies have been reported in the scientific literature examining the effect of exercise intensity on motor, cognitive and psychomotor performance in laboratory settings. These studies examined cognitive tasks, simple and choice reaction tasks, fine and gross motor skills as well as other tasks/skills. Several reviews have also been written summarising the findings on these topics (Etnier et al., 1997; McMorris & Graydon, 2000; Brisswalter, Collardeau & René, 2002). These studies can be classified into three categories: those finding a beneficial effect of fatigue on performance, those finding detrimental effects as well as no effects. More recently, researchers have endeavoured to conduct research outside the closely controlled environment of the laboratory. The more prominent laboratory and field-based research will be reviewed next.

1.8.1 The effects of exercise intensity on cognitive performance

In many sports, especially team and combat sports, participants have to make decisions rapidly and accurately despite great physical exertion. The topic of exercise / fatigue effects on cognitive performance has fascinated researchers for some time. However, despite more than 200 studies being conducted from 1930-1999, the issue of how fatigue impacts on cognitive performance remains unresolved (Brisswalter, Collardeau & René, 2002). A review of this topic was also conducted by Tomporowski and Ellis (1986) but Lemmink and Visscher (2005) propose that the reason why so many questions remain, relates to the diversity of methods chosen to study this topic. Studies relating to this topic have differed with respect to exercise mode, protocol, physical fitness and experience of the participants, as well as the nature and complexity of cognitive tasks. The time of administering the cognitive tasks also differed greatly from study to study. Other authors have also raised some of these points (Etnier et al., 1997; McMorris & Graydon, 2000; Brisswalter, Collardeau & René, 2002). As an example, cognitive tasks have ranged from perceptual discrimination, visual search, memorisation, mental calculation, coincidence-anticipation, Stroop test and problem-solving tasks. It is hardly surprising therefore, that controversies still exist over the effect of exercise on cognition (Hogervorst et al., 1996). Many authors have proposed that if fatigue affects the functioning of the central nervous system, it should especially affect complex, decisional, cognitive tasks (Easterbrook, 1959; Gutin, 1973; Fleury et al., 1981; Kennedy, 1988). Despite this point, it is still unclear how physical exercise may affect simple and complex cognitive processing (Hogervorst et al., 1996).

In terms of fatigue enhancing cognitive performance, several early researchers (Shaw, 1956; Gutin, 1966) suggested that some form of physical activity increases the efficiency of mental or cognitive performance. Aks (1998) investigated the effects of ten minutes of low and high-intensity cycling on response time and accuracy and found that all participants were both faster and more accurate on visual search performance after exercise. While high-intensity exercise produced consistently high scores, low exertion had a more variable influence on performance. Exercise was found to have a significant effect on visual search, with both response times and errors decreasing following exercise. The results were discussed in the context of Easterbrook's (1959) and Nideffer's (1979) theories. McMorris and Graydon (1996) also found that speed of processing on a soccer decision-making task improved with increasing exercise intensity. Similarly, Tenenbaum et al. (1993) tested team handball players and found improved accuracy of decision-making while running at a heart rate of 80% of maximum. Improved cognitive performance, was also found in the more recent work of Brisswalter, Collardeau and René (2002). Interestingly, in some past studies participants were deliberately not tested during exercise to avoid possible attentional effects. It has been hypothesised by some authors (Isaacs & Pohlman, 1991; McMorris & Keen, 1994) that when performance is assessed while exercising, divided attentional mechanisms rather than actual fatigue effects may cause the decrease in performance.

Collardeau, Brisswalter and Audiffren (2001) found this to be true in the experimental work they conducted. Diverse contributing factors have been suggested to underpin the improvement in performance found in these studies. The mediating role of resource allocation is one suggestion to explain the improvements in cognitive performance during exercise.

Within the scientific literature there are also studies past (Pinneo, 1961; Davey, 1973; Hancock & McNaughton, 1986) and present (Chmura, Nazar, & Kaciuba-Uścilko, 1994; McMorris & Keen, 1994; Collardeau et al., 2001) which have found a negative effect of fatigue on cognitive performance. Furthermore, some studies have found no effect. Tomporowski, Ellis and Stephens (1987) for example, concluded that a treadmill run until volitional exhaustion did not affect central processing. Tomporowski (2003) in more recent years has expressed the view that despite a fatigue state, the human body is capable of maintaining cognitive performance.

Other experiments (Davey, 1972 & 1973) measured the effect of controlled amounts of physical activity on mental performance (short-term memory functioning). Results showed a significant improvement in mental performance following small amounts of physical exertion. Moderate amounts of exercise tended to have differing results in different participants. Severe physical exertion however, tended to produce a deterioration in mental performance. These results tend to fit the inverted-U hypothesis. The explanation put forth by Davey (1973) was that under stressful conditions, attention shifts to the central elements of a display, ignoring in the process those pieces of information to the periphery. Reilly and Smith (1986) investigated the effect of exercise intensity (25, 40, 55, 70 and 85% VO_2 max) on a cognitive task. They found that moderate-intensity exercise was associated with peak performance, a pattern again indicative of the inverted-U hypothesis.

With respect to cognitive performance in sport, applied research has been conducted by a number of researchers. For example, Marriott, Reilly and Miles (1993) examined the effect of exercise at heart rate values similar to soccer match play on a soccer-specific decision-making task. Their results showed that decision-making in a soccer context is unaffected by the exercise intensity corresponding to match play. They also found that the skilful players made fewer errors while fatigued, a trend consistent with the predictions of drive theory. Allard, Graham and Paarsalu (1980) in basketball and Starkes and Deakin (1984) also found superior methods of processing task-specific information among the highly skilled players. They found that the low-skilled players firstly exhibited a facilitation and then a decrement in mental performance over 90 minutes. This reflects the mental benefits of warming up in players at this level. In summary, exercise intensity corresponding to match play was found to have no consistent effect upon cognitive function in a simulated soccer context. The authors recommended that further work be conducted on decision-making using dynamic displays of soccer-specific situations.

Hancock and McNaughton (1986) examined the effect of fatigue on six experienced orienteers' visual perception. Fatigue was defined as a stage in which participants were working at or above their anaerobic threshold (determined from a VO_2 max test). Their results suggested that, under the influence of fatigue, an orienteer's ability to perceive visual information is greatly impaired. McMorris and colleagues conducted a series of experiments in the 1990's examining fatigue effects on decision-making. McMorris and Graydon's (1996a, 1996b, 1997a & 1997b) studies showed improvements in the speed of decision-making while exercising at maximal intensity (cycling at MPO). No significant effects for accuracy of decision-making were found however, apart from experiment 2 in their 1997b study, where accuracy was significantly better during exercise at MPO than at rest.

McMorris et al. (1999) examined decision-making performance on a soccer-specific, tachistoscopically presented test. Performance was conducted at rest, while exercising at their adrenaline threshold as well as at their MPO. With respect to the adrenaline threshold, it has been identified in a range of past studies (Podolin, Munger & Mazzeo, 1991; Schneider, McGuiggin & Kamimori, 1992; Hughson, Green & Sharrat, 1995) that there is an exponential increase in catecholamine concentrations of adrenaline and noradrenaline with increasing exercise. The point at which adrenaline demonstrates a significant rise from base concentrations is called the adrenaline threshold. McMorris et al. (1999) calculated the adrenaline threshold by measuring blood lactate responses during an incremental cycle ergometer protocol. Participants were then required to cycle at a power output calculated to elicit their individual adrenaline threshold. The mean concentration of adrenaline, lactate and heart rate at this level were reported to be 0.77 ± 0.45 nmol·l^{-1}, 1.78 ± 0.69 mmol·l^{-1} and 146 ± 20 beats·min^{-1} respectively. Their results however, showed no significant effect of exercise on accuracy but showed speed of decision to be significantly affected by exercise. Speed of decision at rest was also significantly slower than in the other two conditions, which did not differ significantly from one another. McMorris and colleagues discussed their results in terms of allocatable resource theories of arousal and performance.

Royal et al. (2006) examined the effect of a water polo-specific fatigue test on decision-making. A video-based temporally occluded decision-making task (verbal response to various tactical situations) was performed after the fatigue test. Results showed that at very high levels of fatigue, decision-making accuracy was 18% better than at low levels of fatigue (p = .008). They concluded that increases in fatigue level improve decision making in water polo. A more comprehensive study was conducted by Etnier et al. (1997) who carried out a meta-analytic review of 134 studies of both acute and chronic exercise effects on cognitive performance. Overall, they reported a small but significant improvement in cognitive function with an average effect size of 0.25 across all studies. In the subsequent studies using moderate exercise, the average effect size was 0.84. More recently, Tomporowski (2003) reviewed the effects of acute bouts of exercise on cognitive performance either during or after exercise. They concluded that for submaximal aerobic exercise, improvements in cognitive function were generally observed. However, while decision-making in sport is undoubtedly important, according to Knapp (1963), skilled performance in sport requires two important components, decision-making and motor performance. The effect of fatigue on motor performance will therefore be examined next.

1.8.2 The effects of exercise intensity on reaction time

The interactions between cognitive and physiological processes have been studied using reaction time procedures (Arcelin, Delignières & Brisswalter, 1998). The importance of reaction time in sport is undeniable and in sports such as ice hockey, hurling and fencing it is fundamental to successful performance. The effects of fatigue on simple and choice reaction time have been extensively researched within laboratory settings. However, studies investigating fatigue effects on reaction time in applied, field settings are very limited indeed.

In 1965, Weiss introduced a technique for fractionating reaction time into two component parts; pre-motor time and motor time. The procedure according to Kroll and Morris (1976) offers considerable promise for providing a better understanding of the phenomenon of fatigue. The pre-motor component is the period of time from the presentation of the stimulus to the onset of increased electrical activity at the muscle site. The motor time represents the lag between the onset of increased electrical activity and the first demonstrable evidence of a mechanical response. Thus, during pre-motor time the stimulus is perceived, the information is integrated by the CNS, and an action potential is propagated along the efferent pathway to the appropriate muscles. The motor component is a measure of the time involved in the muscle’s electromechanical coupling process and the development of sufficient tension so that the internal resistance opposing movement is overcome. Therefore, any lengthening of premotor time resulting from fatigue would provide a degree of support for the central or neural failure theory and, conversely, an increase in motor time would implicate peripheral or muscular mechanisms (Weiss, 1965 as cited in Stull & Kearney, 1978). Many researchers have used the procedure of fractionating reaction time in an effort to identify the site of fatigue (Kroll, 1973 & 1974; Hayes, 1975; Klimovitch, 1977; Hanson & Lofthus, 1978).

Neither Kroll (1973 & 1974) nor Hayes (1975) were able to show any alteration in either pre-motor or motor time. Klimovitch (1977) however, reported that total reaction time and motor time were increased following two fatiguing hand-grip exercise regimens which resulted in strength decrements of 42% and 55%. Hanson and Lofthus (1978) reported that following a 48% strength loss, both pre-motor time and total reaction time increased while motor time remained unchanged. In Kroll's 1973 study, strength decrements of up to 24% in the knee extensors were elicited through isometric and isotonic exercise and in his 1974 investigation a 17.4% decrement was recorded. Hayes (1975) utilised isometric contractions of the plantar flexion group and degraded initial strength levels from 15% to 34%. However, even though reaction time, or either of its components, seemed to be affected by fatigue, both Kroll (1974) and Morris (1977) reported increases in reflex latency and reflex motor times after the muscle was subjected to fatiguing exercise.

Other studies on this topic have found that fatigue had a detrimental effect on reaction time. For example, selected earlier studies (Crews, 1979; Brisswalter et al., 1995; Legros et al., 1992) found that progressive exercise caused linear decrements in simple reaction time. The issue of causality was raised in many of these studies but not answered. In some studies no effect of fatigue was demonstrated (Lufofs, Wennekens & Van Houtem, 1981). McMorris and Keen (1994) examined the effect of moderate and fatiguing exercise on simple reaction time and found no difference between performance at rest and moderate-fatigue. In their analysis, they hypothesised that for such a simple task, the rise in arousal was simply insufficient to induce a change in performance. They suggested therefore, that their results supported Oxendine's (1984) contention that simple tasks require high arousal for optimal performance.

Other studies on this topic have demonstrated improvements in reaction time following fatigue. For example, in a study by Hogervorst et al. (1996) endurance-trained athletes performed a cycle ergometer endurance test at 75% of their maximal work capacity followed by simple and choice reaction time tests. Both tests showed an increase in speed of performance after exercise relative to baseline. An improvement in choice reaction time has also been reported in many other studies (Delignières, Brisswalter & Legros, 1994; Arcelin, Brisswalter & Delignières, 1997). Paas and Adam (1991) for example, found a significant improvement in performance in a decisional task, at exertion levels located between 75 and 85% of VO_2 max and this improvement was not associated with an increase in error rate. Finally, McMorris and Keen (1994) found that fatiguing exercise (cycling at 100% MPO) significantly improved simple reaction times.

Other studies in the scientific literature showed both facilitation and degradation effects. For example, Levitt and Gutin (1971) made choice reaction time comparisons in relation to heart rate levels and their results were consistent with the inverted-U hypothesis. Therefore, performance improved following moderate-intensity exercise and deteriorated at the highest intensity. Salmela and Ndoye (1986) examined choice reaction time while participants cycled to exhaustion. They found initial facilitation effects at an exercise-induced heart rate of 115 bpm. However, there were universal decrements in performance between 115 and 145 bpm, with differential and progressive effects of exercise on performance beyond 145 bpm in the peripheral fields. Also, at 165 and 180 bpm, peripheral reactions became progressively slower with concomitant increases in the accuracy of signal detection. The results were again consistent with inverted-U and cue utilisation theory.

Legros et al. (1992) examined the influence of fatigue (running at 95% and 125% of VO_2 max) on simple and binary choice reaction time, in expert basketball players. Results showed an impairment in simple reaction time under exertion, but inversely an improvement in choice reaction time. The improvement however, was accompanied by an increase in the error rate. Delignières, Brisswalter and Legros (1994) examined the effect of fatigue on choice reaction time in sports experts. Fatigue was developed by cycling at relative powers corresponding to 20, 40, 60 and 80% of VO_2 max. For the experts, the results showed a consistent increase in performance with increasing exertion levels. Conversely, the performances of the non-expert group deteriorated as exertion increased. The error rate remained stable for each group across conditions. Delignières and colleagues concluded that the improvement in the performance of the experts under high physical exertion was related to additional resource investment. More recent work on this topic has also explored multidimensional models of arousal and allocation of resource theories (McMorris et al., 2005; Royal, 2004; Royal et al., 2006).

Ecologically valid work has been conducted by McMorris et al. (2000) who examined the effect of exercise at the adrenaline threshold and at MPO on the performance of a soccer test requiring decision-making and motor performance. The soccer test examined the participant's speed and accuracy of response. Speed of response was measured by voice reaction time and whole body reaction time. No significant effects of exercise were shown for any of the variables. The authors concluded that because the task was a simple one, even at rest there were sufficient resources to ensure optimal performance. This is supported by the fact that there were no errors in terms of accuracy under any conditions. Eysenck (1992) claimed that it was possible with highly motivated performers to maintain optimal performance of simple tasks even while highly aroused / fatigued. The results of McMorris et al. (2000) support this notion.

Devienne et al. (2000) examined the effects of localised muscular fatigue of the triceps brachii on a 3-choice reaction time fencing task. Their hypotheses were that (1) sub-maximal muscular exercise would decrease pre-motor time and increase motor time in a subsequent choice-reaction task and (2) sub-maximal muscular exercise would increase the attentional and preparatory effects observed in pre-motor time. The task required participants to confront a 3-choice reaction time task which consisted of reaching a target with a sword when a light emitting diode was illuminated. Their results showed that physical exercise did not improve post-exercise, pre-motor time. Muscular fatigue induced by isometric contractions did not increase motor time and lastly, there was no effect of exercise on attentional and preparatory processes in the post-exercise choice-reaction task. In their critical evaluation of this work however, they hypothesised that the exercise task was probably not severe enough to induce a fatigue state. Consequently, this needs consideration when interpreting the findings.

More recently, Sanchez, Barnes and Jones (2004) found that high-intensity exercise (80-85% HRR) resulted in faster visual choice reaction time performances compared to low intensity exercise (40-45% HRR). With respect to moderate-intensity exercise Davranche, Audiffren and Denjean (2006) found an improvement in reaction time performance without being more variable or less accurate. In summary, it is clear from the previous sections here that there is a lack of agreement regarding the effects of exercise on cognition and reaction time. Furthermore, the majority of studies reviewed are laboratory-based with fewer sports-related studies. Consequently, at present no clear pattern has emerged and there is a need for additional research. This is important as many skills in competitive sport include both reactive and/or cognitive components. According to Knapp (1963) skilled performance in sport requires two important components, decision-making and motor performance. The effect of exercise / fatigue on motor performance will therefore be examined next.

1.8.3 The effects of exercise intensity on motor skills: laboratory-based research

It has already been acknowledged that in many team sports there are temporary periods of fatigue. Consequently, team sports provide constantly changing conditions that challenge the cognitive, perceptual and more fundamentally, the physical capacity of a player. Match conditions also amplify the challenge of executing skills in a technically effective manner (Devlin et al., 2001). It is hardly surprising therefore that a substantial number of studies have been conducted across many different sports examining exercise / fatigue effects on fine and gross motor performance. The limitation of this research however, is that it has largely been laboratory-based and so application to sport is limited. With respect to this programme of research, more emphasis will be placed on gross motor tasks as they resemble more closely the type of motor tasks required during sports performance.

Earlier work by Cotton et al. (1974) investigated the effects of localised and total body physical fatigue on gross motor skill performance and concluded that localised muscle fatigue was more detrimental to performance than general fatigue. Evans and Reilly (1980) examined the effect of exercise on a novel gross motor skill. Five exercise levels were developed on a bicycle ergometer with loads set to elicit heart rates of 100, 125, 150, and 175 bpm (based on individual heart rate). Performance was also assessed at rest. Over the last 90 seconds of the exercise intensity, participants threw 20 squash balls at an archery target 4.25m away. Performance was found to deteriorate at the severest exercise level ($p < 0.05$), with no other significant differences found. Their results were discussed in terms of the lack of unanimity with the inverted-U theory. For example, no significant improvement in performance was found before the drop at the very heavy workload. The degree to which anaerobic mechanisms were causally implicated in their study was highlighted and the authors suggested that this merited further investigation. Reilly and Smith (1986) again examined psychomotor performance while cycling at 25, 40, 55, 70 and 85% of VO_2 max. A curve indicative of the inverted-U was found.

In 1991, Berger and Smith-Hale examined the effects of fatigue on the performance of a novel gross motor task. The fatigue criteria/protocol involved performing a maximum number of leg presses at 80% or 60% 1RM to elicit leg strength decrements of 20% and 40% on the last repetition respectively. They found that fatigue had a significant negative effect on gross motor performance. They also noted that some recovery from fatigue occurred after fatigue levels of 20% and 40%. However, the extent of recovery was never complete and fatigue continued to negatively affect the performance trials.

Evans et al. (2003) examined the effect of upper body fatiguing exercise on shooting accuracy. In summary, they found that fatiguing the upper body (arm ergometry at 70% VO_2 peak) significantly decreased both shooting accuracy and shooting precision over time. This was assessed by the number of hits, misses and shot group size (all $p < .001$). Shooting accuracy and precision returned to pre-exercise values within 5 minutes after exercise for all measures except the number of misses, which returned to pre-exercise values 10 minutes after exercise. In their study, shooting accuracy was most diminished immediately after exercise when the heart rate was highest. This is an important point in the context of the current work and the methodological design.

Al-Nakeeb et al. (2003) examined the effect of high-intensity localised muscle fatigue and high-intensity total body fatigue on skilled performance. Localised muscle fatigue was developed using an incremental arm ergometer protocol to 90% HRR. Total body fatigue was developed using an incremental running protocol to 90% HRR. Al-Nakeeb and colleagues examined the effect of both types of high-intensity fatigue on the performance of a gross motor task (throwing a ball at a target) and fine motor task (pegboard test). With respect to the gross motor task, they found that high-intensity localised muscle fatigue was detrimental to performance, but total body fatigue was not. Although a small deterioration in performance was evident following total body fatigue, fundamentally this was not statistically significant. Their results also showed that high-intensity localised and total body fatigue had a detrimental effect on the performance of the fine motor skill. Their results therefore, showed that fine motor skill performance was impaired by high-intensity fatigue (general or localised) and gross motor performance was only impaired by high-intensity localised muscle fatigue. Their findings mirrored very closely those of Cotton et al. (1974). Al-Nakeeb and colleagues discussed their results in terms of attentional narrowing theory (Nideffer, 1979) and increased distractibility (Kahneman, 1973).

In terms of fine motor performance specifically, Williams and Singer (1975) had participants perform the rotary pursuit at rest, low, moderate and high-intensity fatigue. Their data were more indicative of an inverted-J model than an inverted-U model. Spano and Burke (1976) investigated the effect of three work intensities (60%, 75% & 90% HRmax) on rotary pursuit performance. The work / exercise intensity was induced on a cycle ergometer and the results showed a gradual decline in rotary pursuit performance as exercise intensity increased. A significant difference was also found between performance at 60% and 75% and between performance at 75% and 90%. This finding is inconsistent with other studies that reported facilitation in performance with moderate-intensity exercise. The decrement in performance after heavy exercise appears to be consistent however.

Went and El-Sayed (1994) examined rotary pursuit performance while exercising at varying intensities of exercise (25%, 40%, and 85% VO_2 max). Their results indicated that rotary pursuit performance values during exercise were significantly lower ($p < 0.05$) than those observed prior to exercise. Furthermore, rotary pursuit performance during exercise at 85% VO_2 max was significantly lower ($p < 0.05$) than those found during exercise at 25% and 40% VO_2 max. Performance was also examined once the exercise test was completed. Their results showed that performance following the exercise test was significantly higher ($p < 0.05$) than that during the exercise test. Post exercise values were also non-significantly ($p > 0.05$) different from pre-exercise values. The authors concluded that cycling exercise, regardless of its intensity, has an impairing effect on psychomotor task performance. However, this performance was restored once exercise was ceased. It is important however, to consider here that because performance was assessed while exercising, it is not clear whether the effects found were due to divided attention or the ensuing fatigue. This point has been emphasised by previous authors (Isaacs & Pohlman, 1991; McMorris & Keen, 1994) who argued that divided attentional mechanisms rather than actual effects of fatigue caused the decreased performance seen in their studies. It has also long been known that humans have very real limitations in their ability to perform two or more tasks simultaneously (Abernethy, 2001).

Waldron and Anton (1995) examined the effect of exercise (Harvard step test) on performance on the grooved pegboard. Their results showed that exercise on the Harvard step test did not produce an improvement in dexterity / fine motor performance. The results could also be explained by the fact that the muscle groups fatigued were dissimilar to those being used in the criterion task. The authors suggested that exertion plays a more important role in improving visual acuity than enhancing motor skills. Many earlier studies however, suggested that exercise / fatigue has a negative effect on fine motor skills (Carron, 1969; Whitely, 1970; Alderman, 1985).

1.8.4 The effects of exercise intensity on sports skills

Laboratory-based research is limited in terms of its relevance to those conditions on the field of play. Similarly the criterion tasks often bear little resemblance to those skills required during match play. Noakes (2000) offers some insight into why there may be this abundance of laboratory-based research examining fatigue effects on performance. Noakes (2000) claimed that, accustomed to tightly controlled laboratory research, some scientists may be reluctant to undertake field-based studies of performance, in which all the different variables influencing human performance are not easily controlled. However, in more recent years several researchers have attempted to conduct more field-based research and set methodological designs with sound underpinning in terms of ecological validity.

Hoffman et al. (1992) assessed shooting performance among elite biathletes immediately after exercise of various intensities. Shooting performance was assessed from measures of shooting accuracy, shooting precision and stability of hold. It was found that exercise intensity had minimal effect on shooting accuracy and precision for prone shooting, but did affect those measures for shooting in the standard position. In addition, stability of hold was affected more by exercise intensity for shooting in the standing position compared with prone shooting. Transferring the results to competitive biathlon, it is suggested that the intensity of exertion immediately prior to a biathlete shooting, has minimal influence on prone shooting performance, but does affect shooting in the standing position by altering the stability of the hold. In contrast to this, Soldatov (1983) concluded that the exercise intensity prior to the biathlete shooting had little influence on shooting performance in either position for elite biathletes.

Gardiner (2003) more specifically, examined how core musculature responds to fatigue by examining mean EMG amplitude, force development time (FDT) and stick acceleration during a lacrosse shot. Although different in approach to the other previously cited work, their study nevertheless revealed some significant findings. Players in their study underwent an abdominal fatigue protocol. Results showed a significant main effect for decreases in mean EMG amplitude in six to eight core muscles and increases in FDT in one core muscle ($p < 0.05$). They found no change in shot acceleration ($p > 0.05$) following the fatigue protocol. However, they did find changes in mean EMG amplitude and FDT of the lower back muscles suggesting a change in descending control of the core musculature, compensating for abdominal fatigue. The lack of change in stick acceleration suggested compensation by extremity muscles and they concluded that local core fatigue alters muscle recruitment strategies during a lacrosse shot. Examining changes in mean EMG amplitude and FDT when fatigued certainly has potential to bring attention to changes in motor unit recruitment strategies and warrants future investigation.

McMorris et al. (1994) examined the effect of moderate and fatiguing exercise on the performance of a soccer passing test. The soccer passing test was based on a variation of the McDonald (1951) Wall Volley Test. All participants performed this test at rest and following exercise at 70% and 100% of MPO. The test required the participant to kick a soccer ball at a 30cm target, on a wall 7.6m away so that the ball rebounded over the start line. Participants had 90 seconds to score as many points as possible. Total points scored, number of passes, absolute constant error and variable error were examined as dependent variables. Results showed that for total points scored and absolute constant error, performance following exercise at 70% of MPO was significantly ($p < 0.01$) better than in the other two conditions, which did not differ significantly from one another. Regarding the number of passes, the only significant difference lay between the moderate and fatiguing exercise conditions. There was no significant effect of exercise on variable error, nor was there an interaction effect between variables. It was concluded that exercise demonstrated an inverted-U effect on the performance of a passing task. They also noted that the results followed trends predicted by Oxendine (1984) when arousal is high.

McGregor et al. (1999) had players perform a soccer skill test before and immediately after performance of the Loughborough Intermittent Shuttle Test (LIST). This 90 minute intermittent test was designed to simulate the physical demands of soccer match play. The soccer skill test involved dribbling a ball between a line of six cones all three meters apart as fast as possible. Their results showed that performance times were longer after the LIST ($p < 0.05$). They concluded that prolonged intermittent high-intensity running (LIST) resulted in a 5% deterioration in soccer skill level. Ali and Gant (2007) examined the effect of the LIST on the Loughborough Soccer Passing Test (LSPT). Performance on the passing test was conducted every 15 minutes. The results showed that performance on the passing test deteriorated (5.41%) towards the end of the intermittent shuttle test. This deterioration however, was not found to be statistically significant ($p = 0.08$). More recently, Stone and Oliver (2009) examined the effect of a modified version of the LIST on dribbling performance and shooting ability. Both dribbling performance and shooting ability were significantly reduced ($p = .009$ and .012 respectively) following the LIST.

Further work in soccer by Chmura and Jusiak (1994) examined whether a relationship exists between the exercise-induced increase in blood lactate level and the psychomotor performance of Polish first league soccer players. The exercise task in this study consisted of shuttle running and dribbling a ball a distance of 161m at maximum intensity. The performance task was a gross motor choice reaction time task. Post-exercise psychomotor changes displayed a non-uniform course. For example, in the first two minutes, a decrease in performance was observed, then an increase (3-4 minutes) followed by a relatively steady level with a slight tendency to decrease. Six minutes afterwards, psychomotor performance was lower compared to the initial performance. No significant relationship between choice reaction time and blood lactate level was found. The authors hypothesised that the decrease in psychomotor performance was due to disturbances in the mobilisation of attention. They concluded that reduced psychomotor performance observed in the players immediately after the exercise protocol makes it impossible for soccer players to immediately resume effective play. Finally, Chmura and Jusiak (1994) suggested that only after about two minutes does such a player become capable of resuming effective play.

Apriantono et al. (2006) examined a number of biomechanical effects of muscle fatigue on instep kicking, focussing on both the kinetic and kinematic effects of fatigue on kicking performance in football. They hypothesised that induced muscle fatigue in the legs would disturb maximal kicking performance and also lead to a less coordinated kicking motion. Fatigue in their study reduced the quality of ball contact, toe velocity immediately before ball contact and lowered angular velocity of the leg. Both the poorer ball contact and slower leg swing speed resulted in reduced resultant ball velocity after fatigue had been induced. From these results, it can be considered that leg muscle fatigue not only decreased the ability of the muscle to generate force during kicking but also disturbed the effective action of the segmental interaction during the final phase of the kick.

In an effort to address the limitations of past studies in terms of ecological validity, Rampinini et al. (2008) examined the effects of an actual soccer match on short passing performance (assessed using the LSPT). Their results showed that there was a significant decrease in passing precision following the first half (43%) and again following the second half (63%). Total performance scores on the LSPT also deteriorated significantly at the end of the first half compared to baseline and deteriorated further at the end of the second half. The magnitude of differences here was large. They concluded that in soccer, the deterioration in short passing skills may be related to the fatigue accumulated throughout the match as well as to the acute fatigue secondary to high-intensity phases of short duration.

In response to the lack of literature on archery, Squadrone, Rodano and Galozzi (1995) investigated the effects of fatigue on the motor strategy of archers. A simultaneous investigation of different kinds of variables, including kinematic, kinetic and EMG data were performed. In each archer, no significant variation in performance scores was evident with fatigue. Despite this, there was however, a significant increase in bow lateral sway in all participants following the fatigue protocol. The increase ranged from 6% to 39% (mean 20%) and was much more evident in the less skilled archers.

Davey, Thorpe and Williams (2002) examined the effect of fatigue on skilled tennis performance and had participants perform the Loughborough Intermittent Tennis Test (LITT) to volitional exhaustion. This test was conducted on a tennis court and was designed to replicate the demands of actual tennis match play. Groundstroke hitting accuracy was measured against a tennis ball service machine and service accuracy was also measured using a specific scoring system developed by the researchers. The authors found deterioration in some, but not all, strokes. They did however find a 69% decline in groundstroke hitting accuracy following the LITT test and a 30% decline in service accuracy. They suggested that high lactate concentrations could cause a decline in skill execution through inhibition of the contractile processes of the key musculature. Royal et al. (2006) based their study on this idea and examined whether high lactate concentrations caused shooting technique, speed and/or accuracy to deteriorate. They emphasised that fatigue contributes to skill decline as exertion increases (Davey, Thorpe & Williams, 2002; Devlin et al., 2001) and, in their study, endeavoured to examine this using an ecologically valid design. Fatigue states were developed in the swimming pool using a water polo-specific drill aimed at replicating actual match demands. Ball speed and shooting accuracy were also assessed using an ecologically valid goal shooting test. Their results showed that shooting accuracy and ball speed were largely unaffected when tested under similar physiological conditions to that of competitive match performance. In contrast, shooting technique declined as exertion increased.

1.8.5 The effects of exercise intensity on attention

Few areas of sport psychology are as important to overall performance as the area of concentration or attention (Cox, 2002). The major component of concentration is the ability to focus one's attention on the task at hand and thereby not be disturbed or affected by irrelevant internal or external stimuli (Schmid, Peper & Wilson, 2001). Coaches and athletes often link losses in attention, impaired decision-making, lack of focus and other mental breakdowns to fatigue. The sources of fatigue in sport are numerous and inherent given the physical and mental demands placed on the player. In most sporting contexts, players are required to search a complex and dynamic visual display, to attend or concentrate on relevant cues while ignoring irrelevant information (McMorris & Graydon, 1996). However, in competitive sport situations, internal as well as external distractors abound and may potentially influence one's attentional state. Consequently, maintaining the appropriate level and direction of attentional focus may prove difficult.

The ability to allocate and sustain attention to relevant information is crucial to the successful completion of both cognitive and motor tasks (Abernethy, 2001). Additionally, the appropriate allocation of resources and cognitive effort is indicative of successful and even elite performance. In many sports, performance duration is brief, the previewed environment is unstable and the performer must initiate actions with split-second timing. Although focussed attention may seem easy to control, performers are frequently distracted prior to and/or during task execution. Meeusen, Watson and Dvorak (2006) support some of the latter points, stating that increased fatigue has commonly been observed after exercise. The detrimental effects on mental performance according to Collardeau et al. (2001) are typically small, but in sports such as football even minor decrements in mental performance can significantly influence the outcome of a game.

One test which has been widely used in empirical work examining the effect of exercise intensity / fatigue on attention is that of the Stroop colour-word test. Previous studies using the Stroop test in work of this nature are scarce however. Hogervorst et al. (1996) did examine the effect of exercise intensity (cycling at 75% of their maximal work capacity) on the Stroop test. Their results showed an increase in speed of performance after exercise relative to baseline. No more errors were made with the higher speed of performance, thereby showing that exercise at this intensity actually facilitated performance. Miles and Roberts (1998) examined the effect of varying intensities of exercise (60% and 100% maximal exercise work intensity) on performance of the Stroop test. Performance was measured in terms of accuracy (percentage error) and speed (time to complete 30 words). Their results showed that following the 100% intensity, accuracy of performance on the Stroop test was reduced, whereas following the 60% intensity, the speed of performing the Stroop test was improved. Moderate levels of exercise therefore, improved attention whereas high-intensity exercise impaired attention, results consistent with the inverted-U theory.

With respect to concentration more specifically, Thomson (2000) examined athletes' ability to concentrate immediately before and after a treadmill test (protocol/ intensity not provided). The ability to concentrate was found to remain consistent following the treadmill test. Using a different test of concentration, McGregor et al. (1999) had soccer players perform the LIST followed by a mental concentration test. The test involved the identification of numbers ascending from 1 to 100 from a randomised grid. Similarly to Thomson (2000) they found no significant difference between pre-exercise and post-exercise scores for the mental concentration test.

Sibley, Etnier and Le Masurier (2006) found that an acute bout (20 minutes) of moderate-intensity exercise (treadmill) led to improved Stroop performance. However, Al-Nakeeb and Lyons (2007) examined the effect of fatigue at moderate (50% HRR) and high intensities (80% HRR) on Stroop performance. In this study performance was measured while exercising at the desired fatigue intensity on a cycle ergometer. Their results showed no differences in performance across the three experimental conditions (rest, moderate and high-intensity fatigue). There is a lack of consistency in research findings here again and so future investigation is needed.

1.8.6 The effects of exercise intensity on coincidence-anticipation

So far a number of fundamental performance indicators have been examined (reaction time, fine and gross motor skills, sports skills, cognitive performance) with respect to how exercise intensity / fatigue impacts on the performance of such tasks. It is widely known that in sport, there is a myriad of factors which separate expert and novice players. One such factor however, as Tenenbaum, Sar-El and Bar-El (2000) highlight, is that elite athletes have the ability to utilise environmental cues more accurately, select appropriate responses more quickly (Helsen & Pauwels, 1993), control temporal variability more proficiently (Bootsma & Van Wieringen, 1990), and anticipate movements more accurately in a variety of fast ball games. With respect to anticipation, Poulton (1957) called the making of interceptive actions ‘coincidence-anticipation timing’ (CAT). CAT is the ability to predict the arrival of a moving object at a particular point in space and coordinate a movement response with that arrival (Payne, 1986). It combines two different forms of anticipation, effector anticipation and receptor anticipation (Poulton, 1957). With reference to receptor and effector anticipation, Fleury and Bard (1985) suggested that CAT tasks require accurate completion of several phases; (1) a sensory phase, (2) a sensory-motor integration phase during which the time and place of the arriving stimulus and the motor response are determined, and (3) the execution or motor phase. It is clear therefore, that CAT is hugely significant to performance in many sports including basketball, soccer, ice-hockey and hurling.

Researchers have used a variety of strategies to examine anticipation in activities that have tight perception-action coupling and require rapid reactions such as baseball and cricket. The most commonly used device for measuring CAT however, is the Bassin anticipation timer. This device provides reliable measures of CAT (Ramella &

Wiegand, 1983; Payne, 1986) and provides the experimenter with three different types of error scores, namely absolute error (AE), constant error (CE) and variable error (VE). Despite significant advances in our understanding of CAT with respect to practice effects, gender differences and expert / non-expert differences, many unanswered questions still remain. One such question relates to what effect fatigue has on CAT. The role of CAT in sport is clear, yet only a few researchers have examined fatigue effects on this performance indicator.

One of the earliest studies by Bard and Fleury (1978) examined the effect of fatigue to exhaustion (bicycle ergometer) on CAT (press-button task) and found no significant difference in AE with fatigue. Following this, Fleury, Bard and Carrière (1981) used a physical workload, a perceptual workload and a combination of both to induce fatigue. Their results again showed that fatigue had no effect on AE or VE, but there was an improvement in CE following all types of work / fatigue. Finally, Fleury and Bard (1987) examined the effects of different types of metabolic fatigue (induced by treadmill running) on CAT. Their analyses showed that the different fatigue bouts again had no significant effect on absolute error (AE) or variable error (VE) but in this study there was a significant reduction in constant error (CE) following maximal aerobic and anaerobic alactacid efforts.

One of the most commonly cited studies in the literature with respect to fatigue effects on CAT is that of Isaacs and Pohlman (1991). They examined CAT when presented during steady state exercise of varying intensities. Metabolic loads or fatigue levels included unloaded cycling, 25%, 50%, 75% of VO_2 peak and finally cycling at VO_2 peak. Participants were brought up to their assigned metabolic load on the bicycle ergometer and administered 20 timing trials at a fast and a slow speed on the Bassin anticipation timer. This task was chosen by Isaacs and Pohlman, in order to examine Williams, Pottinger and Shapcott's (1985) speculation that differing response situations may have differential effects on the inverted-U relationship. In all three univariate analyses, the level of intensity was found to be significant. Follow-up tests of significance were conducted on each of the three dependent variables. In all three instances, the 100% intensity led to a decrement in CAT performance compared to all other levels. Of the remaining five intensity levels, none were significantly different from one another. Thomson (2000) examined the effect of fatigue (induced by treadmill running) on CAT and concluded that correctness of anticipation was the most important reason why mistakes of a technical or tactical nature occurred during competition. The importance of anticipation to sports performance is therefore, unquestionable.

More recently, Al-Nakeeb et al. (2005) examined the effect of different fatigue levels on anticipation in low and high skilled performers. Moderate (70% HRR) and high-intensity (90% HRR) fatigue states were developed on a rowing ergometer and once the desired intensity was reached, participants completed 30 CAT trials. A fine motor response (press button) was chosen for their study. Repeated measures ANOVA revealed no differences in CE, VE or AE at rest, following moderate and high-intensity fatigue. Similarly, no differences in anticipation performance were found between the low and high skilled performers. The authors argued that the sensory-motor nature of the task performed following fatigue required further investigation. In a follow-up study, Al-Nakeeb and Lyons (2007) examined the effect of moderate (50% HRR) and high-intensity (80% HRR) fatigue on coincidence-anticipation. Performance of the coincidence-anticipation trials (press button) was conducted while exercising in this study and the results yet again showed no differences in performance across the three experimental conditions (rest, moderate and high-intensity fatigue). It seems from the above studies therefore, that fatigue effects on CAT are negligible in many but not all of the past studies. A number of unanswered questions still remain therefore, with respect to the effects of exercise intensity / fatigue effects on CAT. One question relates to the fact that the studies conducted, for the most part, have used fine motor (e.g. press-button) responses. A fundamental question therefore, relates to how exercise intensity / fatigue affects CAT performance when gross motor or sport-specific interceptive tasks are used. This has received little attention and will be explored in this work.

1.9 The effects of exercise intensity on sports-related performance – a quest for ecologically valid results

The research examining the effects of exercise intensity / fatigue on motor performance has been, for the most part, laboratory-based. Far less work has been field-based, with very little work in particular examining sports skills that require explosive muscular effort (Anshel & Novak, 1989). Therefore, despite the acknowledged importance of fatigue on sports performance, very little research has examined the effect of fatiguing exercise on the performance of sports skills (McMorris, 2004). Using laboratory tasks to measure performance in sport is less than desirable. While laboratory tasks allow for greater precision in measuring performance and hence, have high internal validity, they most likely do not relate to “real-life” sport performance and as such lack external validity (Zaichkowsky & Baltzell, 2001). Consequently, the application of these laboratory-based research studies to sport is limited due to the fact that the motor tasks (stabilometer, ladder, or mirror target test) used are remotely related to most sport movements (Berger & Smith-Hale, 1991). This work endeavours therefore, to use tasks which have external or ecological validity.

Additionally, there are many examples in the scientific literature where the findings of laboratory-based work have been discussed and compared to sports performance. Spano and Burke (1976) for example, examined the effect of fatigue on rotary pursuit and in their discussion of the findings state that this type of task most closely models the fine motor performance required of basketball and soccer players. This is questionable, however. In terms of the methods used to generate fatigue states, the most common ones have been reviewed already. However, there are again many compromises in terms of ecological validity. Developing fatigue states from isolated forms of isometric, concentric or eccentric contractions is problematic because in reality, exercise seldom involves a pure form of these types of isolated muscle actions (Komi, 2000). This point has been emphasised by other authors (Jones, 1999) who further add that many previous investigations have used very circumscribed and artificial forms of exercise.

1.9.1 Overview of methodologies

After reviewing the literature a number of shortcomings and limitations are clear. This programme of research will consider these limitations and where possible build on the recommendations of previous researchers. The study of exercise intensity / fatigue effects on performance, like any other research topic, will inevitably have inherent limitations. The more commonly cited and prominent are addressed next.

Firstly, the lack of consistent results regarding the effect of exercise intensity / fatigue on performance may be due to the fact that researchers have used a wide variety of criteria for exercise intensity / fatigue (summarised in Table 1). Therefore, while a fatigue state may have been induced in some studies, it is also possible that it was not in others. Furthermore, in some instances, participants recovered from the previous exercise intensity / fatigue because (a) they only provided a single exercise / fatigue bout and numerous performance trials after it during which the participant recovered or (b) they allowed the participant to recover somewhat during the relatively long performance trial(s) (Godwin & Schmidt, 1979). Performance was not assessed therefore, in a truly fatigued state. In many of the earlier studies, recovery from the exercise / fatigue was allowed to occur during performance of the criterion task (Thomas et al., 1975). For example, Johnston et al. (1998) found that within their participants, some began to recover from the lower extremity fatigue during the performance of the criterion test. More recently, McMorris et al. (2000) chose a criterion task with a mean completion time of 2.33 minutes and acknowledged that a significant amount of replenishment was likely to have occurred during the performance of this task. No differences in performance were found in these investigations. This may be due, in part, to the fact that the entire performance was not assessed in a fatigued state. In terms of recovery, while the depletion of acetylocholine, potassium, adenosine triphosphate, phosphocreatine and increases in muscle lactate will hamper motor control, these biochemicals are quickly replenished following the cessation of exercise particularly by fit athletes (Åstrand et al., 2003). As an example, Kjaer (1989) found as much as a 35% reduction in plasma concentrations of adrenaline within one minute of exercise cessation. The timing of the administration task is also a decisive factor because physiological changes, such as central and plasma catecholamine concentrations, quickly return to basal values (Davranche & Audiffren, 2004). Speed of recovery therefore, can be problematic if measurements are not taken immediately on exercise cessation (Cairns et al., 2005). To summarise, these points emphasise that exercise or fatigue effects may only last for a very short period of time. Additionally, the effects may not be manifested at all, if the interval between cessation of exercise and performance of the criterion task is sufficient for replenishment / recovery to take place.

Secondly, accustomed to the tightly controlled conditions of laboratory research, some scientists may be reluctant to undertake field-based studies of performance in which all the different variables influencing human performance are not easily controlled (Noakes, 2000). Anshel and Novak (1989) in their recommendations for future research also highlighted the need for future research to assess the criterion skill under field conditions rather than laboratory conditions. It is evident from the existing literature that limited attention has been paid to the evaluation of fatigue in the field setting, during dynamic contractions involving larger groups of muscles (Lewis & Fulco, 1998; Åstrand et al., 2003). It has also been outlined earlier in this work that in selective previous research (e.g. Welsh, 1969) the muscle groups fatigued differed to those being used in the criterion task. Unsurprisingly, many of these studies showed no fatigue / exercise intensity effects, and it is highly probably that localised muscle fatigue only affects performance if the muscle groups fatigued are the same as those being used in the criterion task.

Thirdly, one of the most critical limitations of many previous investigations was the failure by investigators to take individual fitness levels into consideration. The level of fitness should be considered in terms of individual tolerance to exercise / fatigue, as this is a factor known to influence performance (Fleury & Bard, 1987). Fleury et al. (1981) also suggested that physical fitness was an important factor, more specifically in resisting disturbances produced by different types of fatigue. A sedentary population, therefore, would be more disturbed in their central processing of information and would present a significant reduction in their performance of similar tasks when using the same experimental procedures. They suggested that all future research needs to take this into consideration.

Finally, in sport, motor skills requiring whole body movements frequently take place during or after exercise (McMorris et al., 1994). Despite this, little research has focussed on the effect of exercise / fatigue on such tasks. In addition, many previous studies have employed performance tasks remotely related to sport movements and used exercise / fatiguing tasks that emphasise the aerobic energy system (Berger & Smith-Hale, 1991). In team sports, many skills required during play are very much gross motor skills requiring whole body movement or actions and so this should be considered by future investigators.

1.10 Justification for the present research

Thus far, the complex and multifaceted concept of fatigue has been examined and working definitions of key terms have been provided. The different methods of developing fatigue states have been reviewed and the merits of each summarised. The importance of developing fatigue states based on the individual fitness level of each participant is fundamental and will underpin each study conducted as part of the current work. The theory underpinning many of the previous studies has been summarised. Some of the limitations of previous work and inconsistencies have also been examined. An overview of previous research findings in the scientific literature examining exercise intensity / fatigue effects on performance has also been provided. It should be clear therefore, from the previous work reviewed, that the literature encompasses many complexities and abounds with inconsistencies.

The topic of fatigue however, has wide ranging practical importance and plays a crucial role in sport, often determining the outcome of games/matches. The empirical work of Chmura and Jusiak (1994) and more recently, Mohr et al. (2003) indicates that homeostasis disturbances are frequently observed in the second half of games leading to mounting central and peripheral fatigue. Furthermore, in soccer, a number of authors

(Mohr, Krustrup & Bangsbo, 2003; Krustrup et al., 2003; Bangsbo, Iaia & Krustrup, 2007) have identified that players experience temporary periods of fatigue during matches. As an example, Mohr et al. (2003) and Krustrup et al. (2003) both found that a player's ability to perform high intensity running and sprinting respectively, were significantly reduced following an intense period of activity in a match.

The ability to repeatedly produce very high-intensity exercise with short recovery periods can be very important for maintaining cognitive, movement and skill performance during matches (Psotta et al., 2005). Despite the acknowledged importance of these temporary periods of fatigue during matches, to date very little research has examined the effect of fatiguing exercise on the performance of sports skills.

Within sports teams there is a continuing emphasis on performance quality and so it is important to understand the factors that mediate performance so that the occurrence of negative consequences (i.e. decreased performance quality) may be reduced. This is also true for positive influences on performance. Only by recognising such influences, can the player actively engage in strategies to address any negative consequences observed. Consequently, the topic of exercise intensity / fatigue effects on sports performance is one that needs to be systematically examined and merits further investigation.

For the reasons outlined above, this work aims to examine the effects of moderate and high-intensity exercise on sports-related performance. The exercise interventions will consist of Tomporowski's (2003) 'brief maximal and sub-maximal' forms. The research will explore how exercise intensity affects a number of key aspects of sports-related performance including the performance of sports skills, attention and anticipation. This research will attempt to use performance tasks that display good ecological validity and develop fatigue states based on individual capacities. Finally, the work will examine whether the main theories of arousal can account for the findings.

1.11 Overview of research studies

This thesis is presented in eight main chapters with five related empirical studies forming the basis of the research. Team sports are the primary focus of this experimental research exploring the effects of exercise intensity on different aspects of sports-related performance.

The initial study examined the effect of moderate and high-intensity exercise on passing performance in soccer. To establish the different exercise intensities, participants firstly performed as many alternate split-squats as possible in one minute. This was designed to elicit their individual capacity in the task and subsequently used to define the moderate and high intensities. The need to control for such intervening variables as the participant's fitness level has been identified by past authors (Anshel & Novak, 1989) as crucial in experiments of this nature. Furthermore, failure to control for physical fitness is one of the reasons underpinning the wide diversity of experimental results found in the literature (Brisswalter, Collardeau & René, 2002). The use of an individual relative workload is recommended therefore. Study one and subsequent studies conducted as part of this program of research sought to consider this.

Past authors (Lewis & Fulco, 1998; Åstrand et al., 2003) have also identified that more attention needs to be paid to the evaluation of fatigue in appropriate field settings during dynamic contractions involving larger groups of muscles. The exercise task (alternate split squats) in study one required dynamic contractions of the same large muscle groups required in the performance test. The performance test (Loughborough Soccer Passing Test) was chosen as it represented an ecologically valid test assessing instep passing accuracy. The test was modified only to ensure that the test was completed within 30 seconds. Key to the design of the initial investigation therefore, was that players reached the desired exercise intensity (based on their individual capacity), immediately thereafter performed the test and completed the performance test within 30 seconds. Speed of recovery is problematic in work of this nature, if measurements are not taken immediately on exercise cessation (Cairns et al., 2005).

The studies conducted as part of this program of research were all designed with this point in mind.

The focus of the research broadened in study two and performance changes across the same intensities were examined in expert and non-expert basketball players. The inclusion of expert and non-expert players was based on selective findings in study one. Selective players (semi-professional) within study one experienced little or no decrement in performance under moderate and high intensity exercise conditions when compared to the rest of the sample. These players were also competing in football at a higher level than the rest of the sample and for this reason study two sought to explore whether the effects of exercise intensity on sports performance were the same regardless of level of expertise. In study two, exercise intensities were again based on a one-minute individual capacity test. The muscle groups in the exercise task (squat thrusts) and performance tasks again were matched. The performance test (AAHPERD Basketball Passing Test) was chosen as it represented an ecologically valid test to assess chest pass accuracy in Basketball. The test was modified again so as to ensure that the test was completed within 30 seconds. The design of the initial two studies therefore, was such that recovery effects were negated as much as possible. The exercise tasks were also more anaerobic in nature due to the well documented importance of all-out, high-intensity efforts within the two respective sports.

In study two, impaired anticipation was a feature of the performance of player's particularly following high-intensity exercise. Players on occasions did not anticipate the pace of the ball correctly leading to players fumbling the ball. This reduced the player's fluency of movement as they passed the ball and moved laterally along the wall. Therefore, poor anticipation essentially led to a spiral of events that reduced overall performance scores. Study three explored the effects of moderate and high intensity exercise on anticipatory skills, namely coincidence anticipation timing. Expert and non-expert players were recruited in this study in an effort to explore further the exercise intensity by level of expertise interaction effects found in study two.

Study three examined the effect of moderate and high-intensity exercise on coincidence anticipation in expert and non-expert Gaelic games players (hurlers). Performance was assessed using the Bassin Anticipation Timer and a sport-specific interceptive movement was employed. The team sport here (Hurling) was chosen due to the fact that high-speed interceptive actions and anticipation are imperative in the game and often determine the outcome of matches. The nature of the exercise task shifted from more anaerobic tasks (study one and two) to an aerobic, running-based protocol (study three). This was revised due to the fact that the limited scientific literature pertaining to Hurling implied a predominance of aerobic metabolism during competitive games. However, as with study one and two, the exercise protocol in study three again accounted for the fitness levels of each individual participant and the performance task was conducted immediately on exercise cessation. The duration of the performance task was also maintained at approximately 30 seconds so as to ensure recovery from the previous exercise did not occur. Study three again revealed an exercise intensity by level of expertise interaction but the nature of the interaction differed from that in study two.

Following on from study three, study four comprised a small-scale investigation that examined the effects of moderate and high-intensity exercise on attention (Stroop Test). This study was conducted in light of the participant’s subjective responses documented post-testing in studies 1-3. These responses revealed that the fatigue sensations participants were experiencing, often made it difficult for them to completely focus their attentions on the performance task. Similar points relating to increased distractibility were raised by a number of participants across the studies following moderate but more commonly, high-intensity exercise. Study four therefore, examined how moderate and high-intensity exercise, induced using the same running protocol as that in study three, effects one’s attention. The study was again designed around participants reaching the desired exercise intensity (based on their individual capacity), immediately thereafter performing the Stroop test and completing the test within 30 seconds.

The final empirical study (study five) examined the effect of moderate and high-intensity exercise on groundstroke accuracy in expert and non-expert tennis players and comprised the most ecologically valid design in terms of exercise and performance tasks. It is also the most significant in terms of sample size. Groundstroke accuracy was assessed using the modified Loughborough Tennis Skills Test, originally developed and validated by Davey, Thorpe and Williams (2002). The exercise protocol was the Loughborough Intermittent Tennis Test, previously validated by Davey, Thorpe and Williams (2003). In the case of study five therefore, the environment, performance test and exercise protocol all had a much higher degree of ecological validity than the protocols employed up to this point.

The focus of study five broadened to also examine whether the effects of exercise intensity on performance differs according to gender or motivation level. The need to examine the effects of exercise on performance in women as well as men has been identified for some time (McGlynn, Laughlin & Rowe, 1979). Both male and female tennis players were recruited for this study whereas in the initial four investigations only male participants were recruited. Finally, study five explored player's achievement goal indicators through the 2 x 2 Achievement Goals Questionnaire for Sport (Conroy, Elliot and Hofer, 2003). This study explored motivation, more specifically achievement motivation in an effort to examine if this personality characteristic provides some insight into how players perform under moderate and high-intensity exercise conditions. In summary, the five related research studies conducted here offer a number of insights into the effects of moderate and high-intensity exercise on sports-related performance.

2.0 PERFORMANCE OF SOCCER PASSING SKILLS FOLLOWING MODERATE AND HIGH-INTENSITY EXERCISE

2.1 Introduction

It has been suggested in several recent review papers on soccer that the behaviour of players and match phenomena attest to the occurrence of fatigue. The distribution of goals scored during football matches shows a bias, in that more goals than predicted are scored towards the end of the game. The explanation for this is likely to be a complex phenomenon (Reilly, 1997). However, it is highly probable that fatigue is a contributing factor. The physiological demand in soccer matches has been intensively studied. In recent years, many review papers have been published (Mohr, Krustrup & Bangsbo, 2005; Stølen et al., 2005; Bangsbo, Mohr & Krustrup, 2006; Bangsbo, Iaia & Krustrup, 2007; Reilly, Drust & Clarke, 2008; Rampinini et al., 2008; Rampinini et al., 2009) specifically relating to match demands and fatigue in soccer.

A number of reviews (Mohr, Krustrup & Bangsbo, 2003; Bangsbo, Iaia & Krustrup, 2007) have suggested that elite soccer players experience temporary fatigue during and towards the end of a match. Reilly (1997) examined the energetics of soccer and emphasised the importance of high-intensity all-out efforts which constitute the anaerobic component of the game. Other authors have identified that the most decisive actions in soccer are covered by means of anaerobic metabolism and these are often crucial in terms of match outcome (Stølen et al., 2005). Linked to this is the view of Szgula, Gawronski and Kalinski (2003) that there are two different patterns of fatigue. Firstly, the effect of short-term, high-intensity effort and secondly, the pattern as a result of long-term exercise. It is clear from recent reviews that the pattern of fatigue resulting from short-term high-intensity effort is fundamental to match outcome in soccer.

To date, a wide diversity of research has been conducted in soccer examining maximal and sub-maximal exercise on decision-making (Marriott, Reilly & Miles, 1993; McMorris & Graydon, 1996a, 1996b, 1997a, 1997b; McMorris et al., 1999; McMorris et al., 2000). More recent research in soccer has investigated the effects of fatiguing exercise on power (Hoffman, Nusse & Kang, 2003), reaction time (Lemmink & Visscher, 2005) and kicking kinematics (Apriantono et al., 2006). The findings of these studies were summarised in chapter one. Given the current interest in this topic and the number of review papers pertaining to fatigue in soccer, much less attention has focused on the effects of fatigue on soccer performance or skills (Oliver, Armstrong & Williams, 2008; Rostgaard et al., 2008). One of the most essential skills for success in soccer is undoubtedly the ability to kick the ball accurately (Flinnoff, Newcomer & Laskowski, 2002). Despite this, remarkably few studies have examined the effect of exercise intensity on passing accuracy in soccer. While the most pertinent of these studies are summarised in section 1.8.4, two studies in particular, have similarity to the present work. McMorris et al. (1994 & 2000) conducted investigations relating to soccer passing performance but the present work is based on key recommendations from these studies. In their 1994 study, McMorris and colleagues modified the McDonald's (1951) Wall Volley Test whereby players completed as many instep passes of a football (typically 32-35 passes) as possible at a target in 1 minute 30 seconds. In the other investigation here, McMorris et al. (2000) used a soccer passing task that lasted 2 minutes 33 seconds to complete. In both studies, high-intensity exercise had no significant impact on the performance of these tasks. McMorris and colleagues acknowledged that recovery effects may have been a confounding variable in the latter study here particularly. Heart rate values prior to and following the performance test were also suggestive of this. McMorris et al. (1994 & 2000) outlined that the detrimental effect of high-intensity or fatiguing exercise may only last for a very short period of time. Furthermore, they added that the effects may not be manifest at all, if the performance time of the criterion task or the delay from exercise cessation to performing the performance task is sufficient for repleinishment to take place. The present study carefully considers these points.

Reilly (1990, as cited in Drust, Reilly & Cable, 2000) provides some possible insights into why there is a dearth of literature relating to this topic. He suggested that many researchers in sport and exercise science have been discouraged in their attempts to study soccer by the lack of available experimental models. In summary, whilst there is a marked aerobic requirement in soccer, recent reviews of match play have identified the importance of high-intensity all-out efforts which constitute the anaerobic component of the game (Reilly, 1997). It has also been postulated that in soccer, the most decisive actions are covered by means of anaerobic metabolism (Stølen et al., 2005). This study therefore, sought to explore the effect of an anaerobic exercise task on performance in soccer. Anaerobic exercise tests involve very high-intensity exercise lasting from one second to several minutes (Skinner & Morgan, 1985). The use of an anaerobic exercise task is considered more appropriate than an aerobic task by some authors (Arnett, DeLuccia & Gilmartin, 2000) and so these points together provided the rationale for using an anaerobic exercise task in this preliminary study.

2.2 Aims of the study

The aims of the present study were to examine the effect of moderate and high-intensity exercise on passing performance in soccer. The present study seeks to address the paucity of research on this topic and consider some of the fundamental limitations of previous work highlighted in section 1.9.1 as well as recommendations by past authors (McMorris et al., 1994 & 2000) relating to studies of this nature. Also fundamental to the aims of this study was an examination of the effect of moderate and high-intensity exercise on passing performance specifically using a performance test that demonstrates ecological validity.

2.3 Method

2.3.1 Participants

Twenty physically active male college students volunteered to participate in this study. Their mean age, stature and body mass was 22.95 ± 5.32 years, 177.95 ± 7.77 cm, and 76.85 ± 12.80 kg respectively. Students consisted of a mixture of collegiate soccer players playing in university competitions. All players were training regularly and participating in at least one competitive match per week. Players were recruited using volunteer and opportunistic sampling methods.

2.3.2 Testing site

All testing was carried out in 21 m x 12 m gymnasium where the temperature was regulated and maintained between 17 - 19^{o} C during all tests. The temperature was measured using a digital barometer (Model BA116, Oregon Scientific, China) prior to each testing session. This gymnasium was well-lit and provided adequate space to carry out the testing required.

2.3.3 Experimental design

This study used a repeated measures design. The procedures used were approved by the Institutional Ethics Committee and a copy of the ethics certificate is presented in Appendix I. A sample informed consent sheet and medical history questionnaire is also presented in Appendices II and III respectively. These were typical of those used in all the studies conducted here. Participants completed both of these forms after being fully informed of the nature and demands of the study.

Twenty participants attended three testing sessions as part of this study. Before each testing session, participants were given ten minutes to warm-up and perform a series of stretches. During the first session each participant was measured for stature and body mass using standard methods and the alternate split squat exercise was demonstrated to each participant after which they performed some familiarisation trials of the split squat technique. To establish the different exercise intensities, participants were required to perform as many alternate split-squats as possible in one minute (Figure 4). The one minute period was chosen here following a pilot study in which this task was evaluated. Participants were instructed during the pilot study to perform as many split squats as possible (i.e. an all-out effort, the point of exhaustion, or the point at which they could not perform any further split squats). For many of the participants, at 50-55 seconds, they found it increasingly difficult to perform further squat thrusts. In some cases participants were forced to stop just prior to the one minute point indicating they were unable to perform any further squat thrusts. Therefore, one minute was deemed a sufficient duration to create maximal levels and yield a person's capacity in the task.

This was then used to define the moderate and high intensities. The rationale for this method of quantifying exercise also relates to a number of more explicit points:

(1) It has been highlighted by some authors (Lewis & Fulco, 1998; Åstrand et al., 2003) that more attention needs to be paid to the evaluation of fatigue in appropriate field settings during dynamic contractions involving larger groups of muscles. The split squat exercise comprised dynamic contractions of large muscle groups. With this exercise, the quadriceps are the primary muscle group and the hamstrings, gluteals and gastrocnemius are the secondary muscle groups. Taken together, the split squat exercise comprised dynamic contractions of a number of large muscle groups.

(2) The split squat exercise impacted heavily on the quadriceps and hamstring muscle groups. These muscle groups are considered essential in terms of skilful performance in soccer (Hamzeh & Head, 2004) and particularly important in terms of passing performance. The muscle groups involved in both the split exercises and passing test therefore were similar.

(3) Speed of recovery is problematic if measurements are not taken immediately on exercise cessation (Cairns et al., 2005). The design and exercise here enabled the researcher to conduct the test in the same environment as the performance test and so there was no delay from achieving the desired exercise intensity and performing the passing test.

(4) This method enabled the investigators to set the two intensities relative to the participant's one minute capability in this test. The need to base exercise intensities on the individual's capacity or fitness level has been acknowledged by past authors (Fleury & Bard, 1987; Fleury et al., 1981) as a fundamental element in studies of this nature.

(5) Reviews of match demands and fatigue in soccer point to the importance of anaerobic components of the game (Reilly, 1997) and all-out efforts (Stølen et al., 2005) in terms of match outcome. The split squat test is anaerobic in nature and is a local rather than a systemic test.

Figure 4. Participant performing alternate split squats

This image has been removed for data protection reasons. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University

Moderate and high exercise intensities were established by calculating 70% and 90% of the maximum number of alternate split squats performed by each participant within a minute. To ensure that each participant was being exercised at the target intensity a metronome (Wittner, Germany) was set to the appropriate cadence required so that the correct number of split squats was performed within one minute. Following on from this session, the participants performed the modified Loughborough Soccer Passing Test (mLSPT) at rest, following moderate and intense exercise. All testing on the three conditions was counterbalanced. Forty-eight-hour intervals were allowed between testing sessions to ensure that participants experienced no effects from the previous testing session. To account for any time-of-day effects, all tests were performed within a time difference of ± 2 hours of the previous test.

To ensure that performance on the passing test was conducted at the target intensity the following guidelines were set: (1) a 2-3 second time lag was allowed from achieving the desired intensity level to performing the task and (2) only eight passes were required to complete the test. The total time to complete the test was on average 20-30 seconds. This was crucial to the experimental design as the recovery process after exercise or fatigue is often considered a limitation in experiments of this nature.

2.3.4 The modified Loughborough Soccer Passing Test (Ali et al., 2003)

The test used in this study was based on a modification of the Loughborough Soccer Passing Test (LSPT) developed by Ali et al. (2003). This test was chosen because it has been shown to be a valid and reliable test of soccer skill for use with university soccer players (Ali et al., 2003 & 2007). The test shows high construct and criterion validity and displays good ecological validity in that it assesses multi-faceted aspects of the game including passing, control and dribbling (Ali et al., 2003 & 2007). The test also factors in magnitude of error and so is a sensitive measure of accuracy which according to Flinnoff, Newcomer and Laskowski (2002) is crucial in tests of kicking accuracy in soccer. Ali et al. (2007) also reported that the reliability of this passing test was high. The statistical procedures used by Ali et al. (2007) to assess reliability considered the recommendations of Atkinson and Nevill (1998) and in so doing, utilised Bland and Altman's (1986) ratio limits of agreement to assess the reliability of the LSPT. This is a more robust method of assessing reliability than more traditional methods such as correlation coefficients (Bland & Altman, 1986 & 1999). Bland and Altman (1999) advocated that the use of correlation to assess agreement is misleading. This is due to the fact that some measures, while they have a small test re-test difference, and therefore a strong relationship, may nevertheless have poor agreement. The best way to measure agreement with tests that display small differences, is to measure the standard deviation of differences, referred to as the coefficient of variation or limits of agreement. They argued that this method enabled the researcher to compare the agreement that the method had to itself, its repeatability more accurately. This was considered by Ali et al. (2007).

A diagrammatic representation of the mLSPT is presented in Figure 5 in Appendix IV. Figure 6 illustrates the set-up of the mLSPT in the present study. The aim of the test was to complete eight passes within a circuit of cones and grids in a clockwise order as quickly and accurately as possible. In the original test 16 passes were completed in an order determined by a second examiner. The rationale for completing 8 passes in a clockwise order was so that the performance task could be completed in a shorter time period (20-30 seconds). This prevented recovery from the ensuing exercise to occur over the course of the performance task and considered key recommendations by McMorris et al. (1994 & 2000). All other aspects of the test procedures, set-up and scoring were consistent with the original test.

Four different coloured target areas measuring 60 x 30 cm were constructed on standard gymnasium benches. The participant started with the ball in the central box and upon the investigator's call they proceeded to dribble the ball into the passing area rectangle, pass the ball against the first target (target A), then control the ball, dribble the ball through the central box and move to the next target (target B). They then continued in this manner, moving from one bench to the next in a clockwise direction until a total of eight passes were made. The ball had to be taken through the central box and out of it before playing the next pass. Additionally, for each pass the ball had to be passed inside the passing area (see Figure 7). The football (Mitre super league indoor football) was standardised for all trials and testing sessions. This ball constituted a 32-panel woven felt ball that weighed 430g and was inflated to a pressure of 12psi.

Figure 6. Set-up of the mLSPT

Figure 7. Participant performing the mLSPT

This image has been removed for data protection reasons. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University

Time penalties were added during the performance of the mLSPT for the following errors:

- 5 seconds for completely missing the bench or hitting the wrong bench
- 3 seconds for missing the target area
- 2 seconds for hitting the yellow target area
- 1 second for hitting the blue target area
- 2 seconds for passing the ball outside the designated area
- 2 seconds for the ball touching any cone
- 1 second for every second taken over the allocated 21.5 seconds to complete the test

Furthermore, one second was deducted from the total time for every time the ball hit the 10 cm strip in the middle of the target (pink strip) as this represents the 'perfect' pass. Total performance therefore, consisted of time taken to complete the eight passes as well as any added time penalties. During the first testing session, participants were given five attempts on the mLSPT to familiarise themselves with the test protocol.

As well as the objective measures, participant judgements about test performances were also made on the score sheets by the investigator and any comments made by the participants in debriefing session were also noted on the score sheets. According to Arnett (2002) the value of qualitative data obtained by participant judgements should not be underestimated, especially in predicting future performance. Constructs such as fatigue and stress are complex and multidimensional and so combining subjective and objective measures is often beneficial. Participant responses can tell us something useful about aspects of the environment to which the organism responds and may affect future behaviour (Arnett, 2002). This was considered important in the context of this work and so implemented accordingly.

2.3.5 Statistical analysis

The preliminary analysis of data explored measures of central tendency (e.g. mean values) and dispersion (e.g. standard deviation) using the analysis of descriptive statistics function in SPSS. The descriptive data are presented in Table 2 and the raw data in Appendix XXII. ANOVA with repeated measures was then carried out on overall performance scores, passing penalties incurred and overall time penalties incurred. The results of these analyses are presented in Table 3 (Appendix V). Because all treatment conditions were planned, a pairwise least significant difference post hoc procedure was used in the case of significant F scores. With each analysis, the residuals of the repeated measures ANOVA were checked for normality using the Shapiro-Wilk test statistic. Homogeneity of variance was evaluated using Mauchly's test of sphericity and when violated, the Greenhouse-Geisser adjustment was used. SPSS Version 17.0 (SPSS Inc., Chicago, IL) was used for all statistical calculations. The level of significance was set at 0.05.

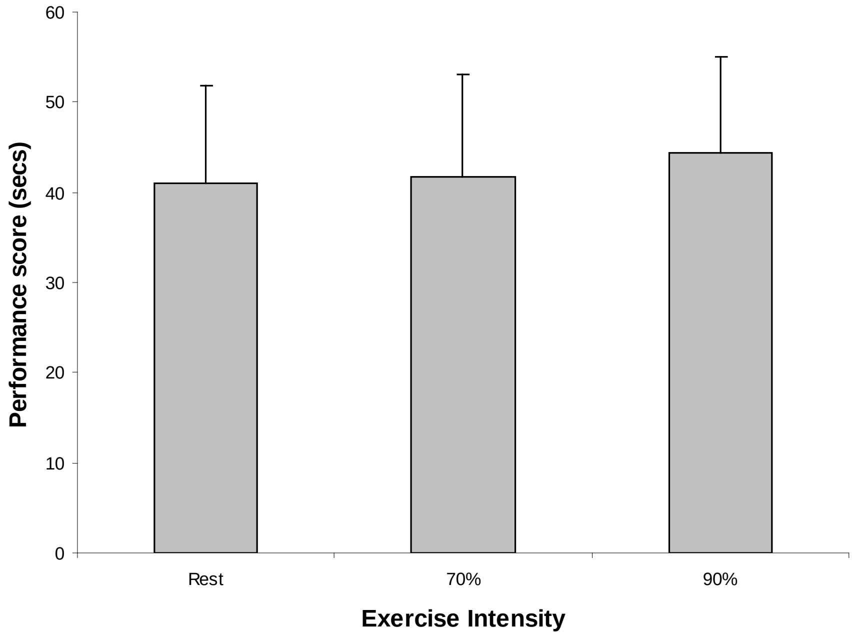
2.4 Results

Table 2. Descriptive data for soccer study

Variable	N	Minimum	Maximum	Mean	SD
No. Squats (100%)	20	97.00	145.00	121.60	14.40
No. Squats (moderate-intensity)	20	87.00	102.00	84.90	10.67
No. Squats (high-intensity)	20	67.00	130.00	109.45	12.91
Performance score (secs) (rest)	20	28.49	74.12	41.07	10.81
Performance score (secs) (moderate-intensity)	20	25.25	80.38	39.84	12.56
Performance score (secs) (high-intensity)	20	26.19	69.40	44.32	10.75
Passing penalties (secs) (rest)	20	4.50	12.00	8.20	2.21
Passing penalties (secs) (moderate-intensity)	20	0.00	13.00	7.80	3.25
Passing penalties (secs) (high-intensity)	20	5.00	14.00	9.95	2.80
Total penalties (secs) (rest)	20	6.50	32.50	13.48	6.10
Total penalties (secs) (moderate-intensity)	20	2.00	36.00	12.65	7.49
Total penalties (secs) (high-intensity)	20	5.00	33.00	17.00	6.94

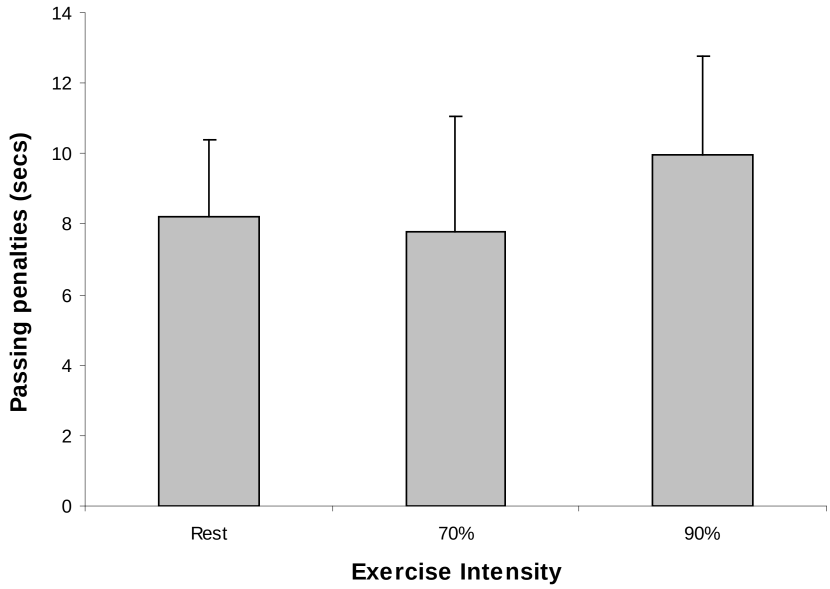
ANOVA with repeated measures revealed a significant ($F_{2,\ 38} = 5.183$, $p = 0.010$, $\eta^2 = .214$) difference between the overall performance scores across the three exercise intensities (rest, 70% & 90%). The Shapiro-Wilk test statistic ($p > 0.05$) revealed that the data were normally distributed. Using the least significant difference adjustment, results indicated a significant ($p = 0.03$) difference between performance scores at rest and scores following high-intensity exercise and a highly significant difference ($p = 0.003$) between scores at moderate and high-intensity. Examination of the descriptive data (Table 2) indicates that the mean scores following rest, moderate and high intensity were 41.07 ± 10.81 seconds, 39.84 ± 12.56 seconds and 44.32 ± 10.74 seconds respectively. This indicates that the best performance was achieved following moderate-intensity exercise while the worst performance was scored following high-intensity exercise. This is illustrated in Figure 8.

Figure 8. Mean performance scores (± SD) on the mLSPT following rest, moderate and high-intensity exercise conditions



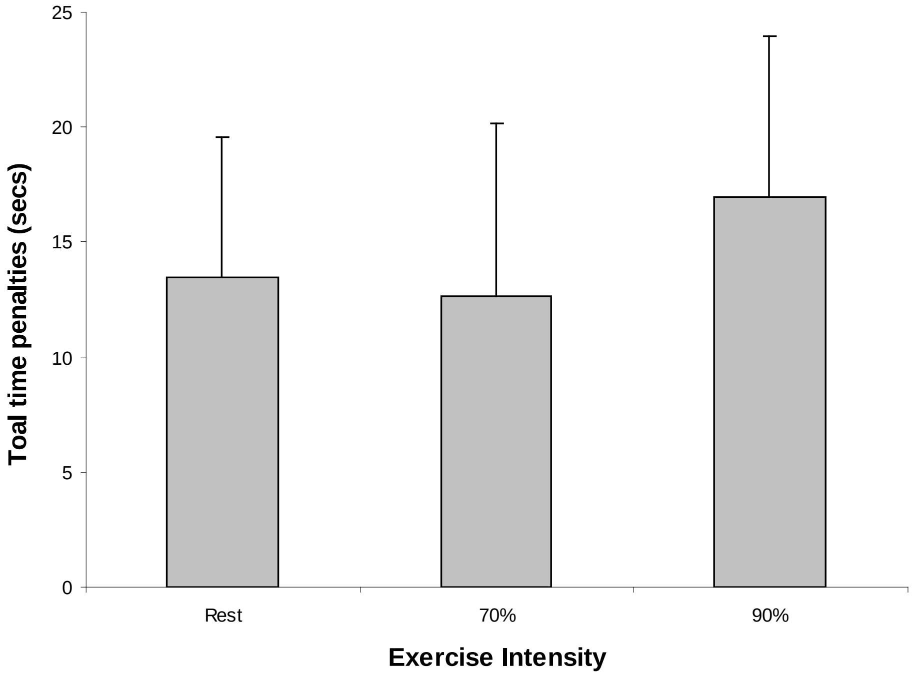
ANOVA with repeated measure also revealed a highly significant ($F_{2,\ 38} = 6.980$, $p = 0.003$, $\eta^2 = .269$) difference between the passing penalties incurred at rest, 70% and 90% exercise intensities (Appendix V). The Shapiro-Wilk test statistic ($p > 0.05$) revealed that the data were normally distributed. Using the least significant difference adjustment, results indicated a highly significant ($p = 0.007$) difference between performance scores at rest and scores following high-intensity exercise and a highly significant difference ($p = 0.001$) between scores at moderate and high-intensity exercise. Examination of the descriptive data (Table 2) indicated that the least number of passing penalties were incurred by participants following moderate-intensity exercise and the most penalties were incurred following high-intensity exercise. Therefore, high-intensity exercise has a detrimental effect on passing accuracy. This is illustrated in Figure 9.

Figure 9. Mean passing penalties (± SD) on the mLSPT following rest, moderate and high-intensity exercise conditions.



ANOVA with repeated measures also revealed a highly significant ($F_{2, 38} = 9.384$, $p < 0.001$, $\eta^2 = .331$) difference between the overall (total) time penalties incurred across the three exercise intensities (Appendix V). The Shapiro-Wilk test statistic ($p > 0.05$) revealed that the data were normally distributed. Using the least significant difference adjustment, results indicated a highly significant ($p = 0.002$) difference between overall time penalties incurred at rest compared to time penalties following high-intensity exercise and a highly significant difference ($p < 0.001$) between the penalties incurred following moderate compared to high-intensity exercise conditions. Examination of the descriptive data (Table 2) illustrates that the least number of overall or combined penalties were incurred by participants following moderate-intensity exercise and the greatest number of overall penalties were awarded following high-intensity exercise. This is illustrated in Figure 10.

Figure 10. Mean total time penalties (± SD) on the mLSPT following rest, moderate and high-intensity exercise conditions



2.5 Discussion

It has been identified in recent reviews on match play demands and fatigue in soccer that players experience temporary fatigue during and towards the end of matches. Because many sports skills are performed under intense exercise conditions, there is a need to assess skilled performance in this condition. This preliminary study examined the effect of moderate and high-intensity exercise on soccer passing performance. The results demonstrate that high-intensity exercise has a detrimental effect on performance of the mLSPT. In other words, performance of sport-specific skills may be impaired following high-intensity exercise of this nature. However, comparing the results of this investigation to previous research is difficult because of the diversity in experimental designs from study to study.

One study with similarities to this work is that of McMorris et al. (1994) who examined the effect of moderate and fatiguing exercise on soccer passing performance. Three exercise intensities were set (rest, 70% MPO & 100% MPO). The test was based on a modification of the McDonald (1951) Wall Volley Test where participants were required to kick a soccer ball at a 30 cm target, on a wall 7.6 m away so that the ball rebounded over the start line. Participants had 90 seconds to score as many points as possible. MANOVA showed that for total points scored and absolute constant error, performance following exercise at 70% of MPO was significantly ($p < 0.01$) better than in the other two conditions. The results of the present study also revealed that performance following moderate-intensity exercise was significantly better than that following high-intensity exercise. Furthermore, this study showed that performance following moderate-intensity exercise was marginally better than the resting scores, but this difference was not statistically significant. In terms of performance following high-intensity exercise however, the results show some contrast to those of McMorris et al. (1994). In the present study, a significant ($p = 0.03$) difference was found between performance at rest and that following high-intensity exercise, with a deterioration in performance clearly evident following high-intensity exercise. McMorris et al. (1994) however, found no difference between performance at rest and performance following high-intensity exercise. It should be noted that the performance tests and mode of exercise differ in both studies. Consequently, any comparisons drawn need to be interpreted with these methodological differences in mind.

More recently, Ali and Gant (2007) examined the effect of a 90-minute intermittent shuttle running test on the LSPT. Performance on the passing test was conducted every 15 minutes. The results showed that performance deteriorated (5.4%) towards the end of the intermittent shuttle running test. This deterioration however, was not found to be statistically significant ($p > 0.05$). In comparative terms, the deterioration in performance in their study was shown to be 5% while in this investigation the deterioration from rest to high-intensity exercise was 7.9%. This may be due to the fact the exercise protocol was more intense in the present study when compared to the intermittent shuttle running protocol of Ali and Gant (2007), hence the greater deterioration in the present work. McGregor et al. (1999) also examined the influence of intermittent high-intensity shuttle running on the performance of a soccer skill. In their study, the skill test involved dribbling a soccer ball between a line of six cones as fast as possible. Although the primary focus of their research was fluid ingestion effects, they found that in the absence of fluid ingestion of any kind, there was a 5% deterioration in soccer performance following the intermittent shuttle test ($p < 0.05$). Despite a somewhat different emphasis, this finding is significant as is the fact that both this study and that by Ali and Gant (2007) show the same percentage decline in performance and both studies used intermittent shuttle tests to induce what they termed, a ‘fatigue state’.

Other soccer specific research has been conducted by Chmura and Jusiak (1994) who examined whether exercise-induced increases in blood lactate level affected the psychomotor performance of league one soccer players. Increased blood lactate states were induced by participants performing a soccer dribbling test consisting of shuttle running and dribbling a distance of 161 m at maximum intensity. The most significant finding was that in the two minutes following the dribbling test there was a decrease in psychomotor performance, but after six minutes performance returned to resting levels. The authors hypothesised that the decreased psychomotor performance was due to disturbances in the mobilisation of attention. They concluded that reduced psychomotor performance observed in the players immediately after the exercise protocol (and typical of a match), makes it impossible for soccer players to immediately resume effective play. The results of the initial investigation also demonstrate this to be the case, particularly if the players are subjected to high levels of exercise which is more localised in nature.

The findings from the preliminary study also support more recent studies on soccer by Stone and Oliver (2009) as well as the findings of Rampinini et al. (2008) in terms of the fact that all of these studies also found a significant deterioration in soccer performance following fatigue. The results of this initial investigation reinforce the results of a number of laboratory-based studies examining the effects of exercise intensity on gross motor skills (Williams & Singer, 1975; Went & El-Sayed, 1994), and fine motor skills (Evans et al., 2003). This study again supports the conclusions of Al-Nakeeb et al. (2003) who found a deterioration in gross motor performance following high-intensity localised muscle fatigue. Just as the findings of this work mirror those of other prior research, the results are not consistent with a variety of laboratory and field-based research. For example, the findings are very much contrary to research conducted on archery (Squadrone, Rodano & Galozzi, 1995) and water polo (Royal et al., 2006) where no differences in shooting performance were found with fatigue.

It is interesting to note that in the study by Royal et al. (2006) the type of fatigue was based on typical requirements of the sport (water-polo) and as a result they used a general fatiguing task. In their study this type of fatigue had no effect on shooting performance. In the research by Al-Nakeeb et al. (2003) they used both a localised fatiguing task (arm-cranking) and a general fatiguing task (running) in an attempt to examine how both forms at a high-intensity, impact on the performance of a gross motor task. They found that general fatigue had no effect on the performance of the gross-motor task. Consequently, both Al-Nakeeb et al. (2003) and Royal et al. (2006) found that general fatigue had no effect on the performance of gross motor tasks. However, Al-Nakeeb et al. (2003) found a significant deterioration in the performance of the gross motor task following high-intensity localised muscle fatigue, a finding mirrored in the present study. In light of these findings, it could be argued that while localised muscle fatigue at a high-intensity impacts negatively on the performance of a gross motor task, general forms of exercise / fatigue such as those induced by aerobic-type protocols, do not have the same detrimental impact on performance.

In section 1.6 various theories of arousal were examined in an attempt to provide sound theoretical underpinning which may explain how arousal or sub-maximal and maximal exercise states impact on performance. One theory briefly reviewed was that of drive theory and if one considers the task in this study as not well learned, then the results provide partial support for the predictions of Hull (1943), namely the deterioration following high-intensity exercise. The results of this study also provide some support for the predictions of inverted-U theory. Performance was optimal following moderate-intensity exercise and so there is some initial evidence here at least to support the claims of Yerkes and Dodson (1908). The deterioration in performance following high-intensity exercise however, indicates that the effect may be more indicative of an inverted-J. Yerkes and Dodson (1908) also emphasised the importance of task complexity in terms of their theory and the results of this study again are not consistent with the view of Oxendine (1984) that simple skills will be performed optimally following maximal levels of exercise. The passing test used in this study required strength, speed and ballistic movements and so would be classified as simple according to Billing's (1980) taxonomy. It is plausible however, that Kahneman's (1973) multidimensional allocation of resources theory may provide some theoretical underpinning for the preliminary results found here. Kahneman claimed that at high levels of arousal, it was impossible for effort to totally overcome the negative effects of arousal sufficiently to ensure optimal allocation of resources. Consequently, when arousal is high, performance will be less than optimal as cognitive effort cannot focus attention solely on task-relevant information. The deterioration observed in this study following high-intensity exercise may be testament to the points outlined here by Kahneman (1973). This is explored further in chapter seven.

Participants' behaviour and feedback post-testing again provided some insight into how exercise intensity impacts on the performance of such a task. It was very evident for example, that the decrement in performance in this study following high-intensity exercise was due in part at least, to the discomfort experienced by the participants and a disruption in motor control. Many participants were very unsteady immediately following the intense exercise condition and during the early stages of the performance test. Apriantono et al. (2006) found that induced leg muscle fatigue disturbs maximal kicking performance and also leads to a less coordinated kicking motion, results which seemed manifest in this study. Participants in the debriefing session also indicated frequently that they felt a distinct lack of power following high-intensity exercise. One participant described how he had 'nothing left in his legs'. In terms of performance outcome, this manifested itself through decreased ball speed, inaccurate passes and participants losing control of the ball, all of which incurred time penalties. Therefore, one may conclude that the decrement in performance on the soccer passing test could be due directly or indirectly to the inability of the specific muscle groups to cope with the demands of the task in terms of speed, accuracy or both. The loss of force or functional integrity observed here following short-duration, high-intensity exercise, may be due to a number of potential neuromuscular mechanisms or failure at one or more sites in the neuromuscular system. The neuromuscular mechanisms here may include; (1) alteration in the composition and structure of the membranes or myofibrillar complex, (2) alterations in ionic balance, (3) reductions in free energy availability and (4) direct inhibition of specific processes as a result of elevation in the concentration of metabolic by-products. Some of the more commonly cited metabolic by-products include adenosine diphosphate and monophosphate (ADP & AMP), inosine monophosphate (IMP), inorganic phosphate (P_i), hydrogen ions (H^+) as well as a number of glycolytic intermediates (Boobis, Williams & Wooten, 1993; Green, 1990). As an example, both P_i and H^+ increase with anaerobic-type exercise and are known to inhibit peak force. Some of the other metabolic by-products listed here result in feedback inhibition of metabolic pathways involved in ATP regeneration such as anaerobic glycolysis (Hultman & Sjöholm, 1983), or direct inhibition/disturbance of the excitation-contraction process itself (Green, 1990). Finally, Fitts (1994) identifies that with short-duration, high-intensity exercise, disturbances in excitation-contraction coupling such as a conduction block of the action potential, or an inhibition in sarcoplasmic reticulum calcium release are more likely to occur. Consequently, a number of neuromuscular mechanisms may underlie the symptoms and manifestations observed here.

Given that the participants clearly felt discomfort in their legs, it may be that the predictions of Nideffer (1979) are true in terms of the initial findings here. According to Nideffer (1979) following high-intensity fatigue, there is often an internalising of attention as the participant focuses on the internal signals of pain and fatigue rather than upon the external stimuli leading to a decrement in performance. Some of the participants' responses relating to how they felt during the performance task, following high-intensity exercise are attest to this, but further research is required to examine this more explicitly.

One significant finding which merits further exploration was the fact that two of the participants, as well as playing collegiate soccer for the university, also played with semi-professional football clubs. In both cases, there was very little deterioration in their performance following high-intensity exercise. Therefore, while they exhibited performance improvement following moderate-intensity exercise, only a small deterioration in their performances was evident following high-intensity exercise. This indicates that the level of expertise may influence how exercise intensity affects performance. Their training status may also be important here also. Therefore, whether experts can offset the negative effects of high-intensity exercise certainly warrants further investigation and is considered in subsequent chapters.

2.6 Conclusions

To summarise, the results of this study demonstrated a potential decrement in soccer passing and control following a short bout of high-intensity exercise. The results of this study provide some support for the claim that performance under maximal exercise or fatigue conditions is frequently accompanied by a decline in skilled performance (Mohr, Krustrup & Bangsbo, 2003). Performance following moderate-intensity exercise however, was slightly better than that at rest with fewer passing and control errors and this may be equally significant in terms of match performance in soccer, with possible implications for warming up / re-warming after half-time in soccer.

There are also a number of interesting findings with respect to the underlying theories of arousal. It is clear that some theories (drive theory and inverted-U theory) may provide a degree of support for the findings. The trend in the initial results however, is more indicative of an inverted-J effect as performance deteriorated following high-intensity exercise compared to resting levels. The results also fail to support the claims of Yerkes and Dodson (1908) and Oxendine (1984) with respect to task complexity.

This may link to the fact that the nature of the task being conducted here, while it constitutes a very difficult and physically stressful activity may still not lead to to the increases in arousal level which form the basis of the work of Yerkes and Dodson (1908), Oxendine (1984) and Hull (1943).

Some of the findings of the initial study are consistent with the predictions of Kahneman's (1973) multidimensional allocation of resources theory. Kahneman's (1973) cognitive energetic model regards the total amount of resources which exist in a single undifferentiated pool as limited. The availability of resources depends on the level of arousal which in turn, is determined by two sources, task demand and several other sources such as stimulus intensity, anxiety or exercise (Dietrich & Audiffren, 2011). The model postulates an allocation policy mechanism that directs and supervises the allotment of resources. The level of arousal, then corresponds to the amount of available resources and decrements in performance occur when task demands exceed the resource availability. This may account for the deterioration in performance observed here. Kahneman assumed that there is a general, non-specific pool of energetic resources that supports all functions and predicts performance decline when exercise and the performance task compete for these resources. This will be explored further in chapter seven.

3.0 THE EFFECTS OF MODERATE AND HIGH-INTENSITY EXERCISE ON PASSING PERFORMANCE AMONG EXPERT AND NON-EXPERT BASKETBALL PLAYERS

3.1 Introduction

The present chapter describes a study examining the effect of moderate and high-intensity exercise on basketball passing performance. Basketball shares some characteristics with soccer in that it is a game of continuously changing tempo, requiring speed, acceleration, explosive movements and high-speed play. The game comprises intermittent exercise bouts of short, intense activity punctuating longer periods of moderate-intensity exercise. The game also involves skills that must be applied dynamically, explosively and repeatedly (Gore, 2000). According to Hoffman, Stavsky and Falk (1995) high-intensity, moderate duration exercise and fluid restriction are some of the factors which may be detrimental to basketball performance.

The present study further extends the work conducted in chapter two and considers its recommendations. This chapter therefore, builds on the initial work conducted but seeks to address a number of fundamental issues raised in the soccer study which are central to understanding the effect of exercise intensity on sports performance. The task used in the soccer study required close ball control within a confined space, spatial awareness of the cones within the shooting grid, dribbling, as well as weighted instep passing of the ball. The task was therefore demanding in terms of a range of skills. In the present study, a more simplified task was used, which focused on passing accuracy alone. This enabled the researcher to examine further the claims of Oxendine (1984) with respect to task complexity. In the soccer study the results at both exercise intensities supported the view of Oxendine (1984) that when task complexity is high, moderate levels of arousal will result in optimal performance, while high levels will cause a deterioration in performance. However, Oxendine (1984) also claimed that when a task is simple, high levels of arousal are required for optimal performance to be exhibited. The present study explored this further using a task which would be classified as simple according to Billing (1980). This is due to the fact that perceptually all the necessary stimuli are available, a mimimum number are required for the task and and there are no conflicting stimuli. The task in this investigation does not include a decisional aspect and the motor aspect of the task requires speed and ballistic movement but limited to a small number of key muscle actions.

Secondly, this study explored whether exercise effects on performance are the same in expert and non-expert players. In the soccer study little or no deterioration in performance following high-intensity exercise was found in those participants who, as well as playing collegiate soccer, also play at semi-professional club level. The present study aims to further explore whether the effects of exercise intensity are the same in experts and non-experts.

It is widely acknowledged that there are a myriad of factors which separate expert and non-expert players in sport. Among the many factors, experts have superior technical expertise (Starkes, 2000), perceptual expertise (Abernethy, 1988), cognitive expertise (Williams et al., 1993) tactical expertise, as well as better decision-making and visual search patterns (Goulet, Bard & Fleury, 1989, Williams & Davids, 1998, Savelsbergh et al., 2002). Much research also suggests that elite athletes are better able to utilise environmental cues more accurately, control temporal variability more proficiently (Bootsma & Van Wieringen, 1990) and select appropriate responses more quickly (Helsen & Pauwels, 1993). Ishigaki and Mayao (1993) even found that experienced athletes had greater dynamic visual acuity than inexperienced athletes. A study by Lidor, Argov and Daniel (1998) found that expert team handball players threw faster, more accurately and responded more rapidly than novice players. Consequently, the studies cited here have been very successful in identifying the important characteristics that discriminate between expert and non-expert players. However, there is a lack of research examining how performers at different levels of expertise perform under different exercise intensities. One study which did attempt to examine the effects of physical fatigue on motor control in highly skilled and recreational players was that of Aune, Ingvaldsen and Ettema (2008). They examined the effects of serial fatigue using a custom-built apparatus on table tennis hitting accuracy. The protocol was based on a series of four minute stages where the players were required to work at one-third of their maximal isometric force. Their aim was to develop strong fatiguing demand on the local metabolic system (Aune, Ingvaldsen & Ettema, 2008). Their results showed that the highly skilled players were capable of maintaining high accuracy performance during fatigue, but the recreational players' performance decreased significantly following fatigue (p = .005). They concluded that expertise enhances the potential to adjust motor co-ordination strategies as a reaction to induced physical fatigue (Aune, Ingvaldsen & Ettema, 2008).

3.2 Aims and research hypotheses

The review of literature has indicated that few studies have examined the effects of exercise intensity on basketball-passing using expert and non-expert basketball players. In view of the findings from the initial investigation, this study firstly aimed to investigate the effects of moderate and high-intensity exercise on basketball passing performance. The second aim of this study was to explore whether the effects of exercise on performance are the same in expert and non-expert basketball players. The following research hypotheses are explored in this study:

1) Basketball passing performance will deteriorate significantly following high-intensity exercise, compared to rest and moderate-intensity exercise conditions.
2) There will be a significant difference between the performance of expert and non-expert basketball player’s across the three exercise conditions.

3.3 Method

3.3.1 Participants

Ten physically active male college students volunteered to participate as the non-expert basketball players. Their mean age, stature and body mass was 23.40 ± 3.30 years, 176.50 ± 9.23 cm, and 80.50 ± 17.83 kg respectively. Ten expert male basketball players also participated in the study and consisted of a mixture of national division one and two players. Their mean age, stature and body mass was 22.50 ± 1.26 years, 182.50 ± 6.09 cm, and 87.80 ± 12.72 kg respectively. The players were recruited using volunteer and opportunistic sampling methods.

3.3.2 Testing site

All testing was carried out in a 37m x 18m sports hall where the temperature was regulated and maintained between 16 - 19^{o} C during all tests. The temperature was monitored using a digital barometer (Model BA116, Oregon Scientific, China). This room was well-lit and adequate space was available to carry out the testing required.

3.3.3 Experimental design

This study used a mixed factoral design. Each participant provided informed consent and a medical history questionnaire after being fully informed of the nature and demands of the study. All procedures were reviewed and approved by the Institutional Ethics Committee. The passing test used in this study was a modified version of the basketball-passing test developed by the American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD) in 1984. Subsequent to the measurement of stature and body mass, each participant was given instructions, a demonstration and habituated with the passing test and squat thrust exercise. Participants were then given a 5-10 minute warm-up prior to their performance under moderate and intense exercise conditions. To establish the different exercise intensities, participants were required to exercise to volitional exhaustion by performing as many squat thrusts as possible in one minute (Figure 11). The one minute period was chosen here again subsequent to a pilot study where this task was evaluated. Participants were instructed to perform as many squat thrusts as possible (i.e. an all-out effort, the point of exhaustion, or the point at which they could not perform any further squat thrusts). For many of the participants, one minute was sufficient time for the participants to reach maximal states and yield the individual's capacity in the task. This maximal workload or capacity was then used to define the moderate and high-intensity exercise conditions. These were established by calculating 70% and 90% of the maximum number of squat thrusts performed within the one minute timed period.

Figure 11. Participant performing squat thrusts

This image has been removed for data protection reasons. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University

The rationale for this method and criteria of quantifying exercise intensity are again based on a number of fundamental points:

(1) The need to evaluate fatigue in appropriate field settings using dynamic contractions involving large groups of muscles (Lewis & Fulco, 1998; Åstrand et al., 2003). The squat thrust exercise comprised dynamic contractions of a number of large muscle groups. With this exercise, the quadriceps, hamstrings, gluteals and triceps are the main muscle groups recruited, with the deltoids acting as fixators. Taken together, the squat thrust exercise comprised dynamic contractions of a number of large muscle groups.

(2) The exercise task impacted heavily on the lower body muscle groups used in the passing test (gluteals, quadriceps and hamstring muscle groups). These muscle

groups were recruited throughout the performance test as the participant was required to squat down when passing the ball to the lower targets (Figure 14) and when catching the ball as it returned from the wall. The exercise task also impacted on muscle groups in the upper body (such as the deltoids) as they act as fixators as well as the triceps. These muscle groups are also important in terms of performing the basketball passing task. The muscle groups involved in both the squat thrust exercises and passing test therefore were similar.

(3) Speed of recovery is problematic if measurements are not taken immediately on exercise cessation (Cairns et al., 2005). The design and exercise here enabled the researcher to conduct the test in the same environment as the performance test and so there was no delay from achieving the desired exercise intensity and performing the passing test.

(4) This method enabled the investigators to set the two intensities relative to the participant's one minute capability in this test. The need to base exercise intensities on the individual's capacity or fitness level has been acknowledged by past authors (Fleury & Bard, 1987; Fleury et al., 1981) as a fundamental element in studies of this nature.

(5) Current literature highlights that there is a considerable anaerobic element in the game of basketball (Ben Abdelkrim, Al Fazzaa & El Ati, 2006; Crisafulli et al., 2002; Hoffman & Maresh, 2000; McInnes et al., 1995). The squat thrust exercise again is anaerobic in nature and is a local rather than a systemic test. It is constructed so as to assess the ability of a muscle group to perform short maximal or supra-maximal exercise.

Following on from this, the participants performed the basketball-passing test under three conditions: rest, 70% and 90% of maximal repetitions within a minute. To ensure that each participant was being exercised to the correct intensity a metronome (Wittner, Germany) was set to the appropriate cadence required. All testing on the three conditions was counterbalanced. In order to minimise the effects of the previous testing, at least twenty-four hour intervals were given between successive testing sessions. To account for any time-of-day effects, all tests were performed within a time difference of ± 2 hours of the first test.

3.3.4 The modified AAHPERD (1984) Basketball Passing Test

This test was chosen because the test has been shown to be an appropriate test for use with senior high-school basketball players. Validity coefficients of .37 to .91 are reported for individual test items in the AAHPERD battery of tests. Criterion measures of subjective ratings of skill in shooting and game performance were used (AAHPERD, 1984, as cited in Strand & Wilson 1993, p.95). The test-retest approach computed reliability coefficients of .84 to .97. Despite this, Bland and Altman (1986) have concluded that traditional methods of assessing repeatability such as that used here (e.g. Pearson's r) have limitations and a better, more robust method is to measure the standard deviation of differences or the coefficient of variation (limits of agreement). For the purposes of completeness, this warrants mentioning here. The test also requires the participant to pass the ball quickly and accurately, two factors which Krause, Meyer and Meyer (1999) believe are fundamental elements of good passing. A diagrammatic representation of the test is presented in Figure 12 in Appendix VI. The set-up of the passing test is shown in Figure 13. A restraining line 7.92m in length was marked out on the floor 2.44m from, and parallel to, the testing wall. On the testing wall, six boxes measuring 61cm by 61cm were marked out all 61cm apart. Moving from the left side of the testing wall, targets A, C and E have their base 1.52m from the floor while targets B, D and F have their base 91cm from the floor.

Figure 13. Set-up of the AAHPERD (1984) Basketball Passing Test

The participant was required to stand behind the 2.44 m restraining line, holding a basketball and facing the far left wall target (A). The experimenter then played a CD which emitted a three-bleep countdown, and the fourth bleep signalled the start of the test. Following the fourth bleep, the participant performed a chest pass to the first target square (A), recovered the ball while moving to the second target square (B) and performed a chest pass to the second target (B). They continued this action until they reached the last target (F). While at the last target (F), they performed two chest passes and then repeated the sequence by moving to the left passing at targets E, D, C and so on (Figure 14). The only modification to the test was that after 30 seconds the CD emitted another bleep which signaled the end of the test. Each participant was given one practice trial to familiarise themselves with the test protocol. The use of a CD to time the test was intended to simplify the testing, eliminate timing errors and free the researcher to score the test and write down any observations regarding the testing. During the passing test, only chest passes were allowed and participants were instructed to perform as many passes as possible in 30 seconds. The basketball (Baden Equiliser) was standardised for all trials and testing sessions. This ball (composition rubber) weighed 550g and was inflated to a pressure of 8psi. The scoring of the test was as follows:

- Two points were awarded for each chest pass that hit in the target or on the target lines.
- One point was awarded for every pass that hit between the targets.
- No points were awarded if a player’s foot was on or over the restraining line, or if a pass other than a chest pass was used.

Figure 14. Participant performing the AAHPERD (1984) Basketball Passing Test

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The test score was obtained by totalling all the points scored over the duration of the thirty-second test. To ensure that performance on the passing test was again conducted at the required intensity, the following guidelines were set; (1) only a very short time lag (1-2 seconds) was allowed from achieving the desired exercise intensity to performing the task (2) only one thirty-second test was performed. In the original test, two thirty-second tests are administered. This was the only modification made to the test and served to ensure that recovery from the preceding exercise was not possible. All procedures were reviewed and approved by the Institutional Ethics Committee.

3.3.5 Statistical Analysis

The preliminary analysis of data explored measures of central tendency (e.g. mean values) and dispersion (e.g. standard deviation) using the analysis of descriptive statistics function in SPSS. The descriptive statistics are presented in Table 6 and the raw data in Appendix XXII. A 3 x 2 mixed ANOVA was carried out on performance scores. The within-subject factors were performance at rest, performance following moderate-intensity exercise and performance following high-intensity exercise. The between-subject factor was expertise level. Because all treatment conditions were planned, a pairwise least significant difference post hoc procedure was used in the case of significant F scores. The residuals of the 3 x 2 mixed ANOVA were checked for normality using the Shapiro-Wilk test statistic. Homogeneity of variance was evaluated using Mauchly's test of sphericity and when violated, the Greenhouse-Geisser adjustment was used. Additional between-group analyses were also conducted using three separate independent t-tests. The first t-test examined the difference between the changes in scores (Δ) from the rest condition to moderate-intensity exercise between the experts and non-experts. The second examined the difference between the changes in scores from the rest condition to high-intensity exercise and the third explored the changes in scores from the moderate to high-intensity exercise conditions. SPSS Version 17.0 (SPSS Inc., Chicago, IL) was used for all statistical calculations. The level of significance was set at 0.05. The results of the different analyses here are presented in full in Tables 4 & 5 (Appendix VII).

3.4 Results

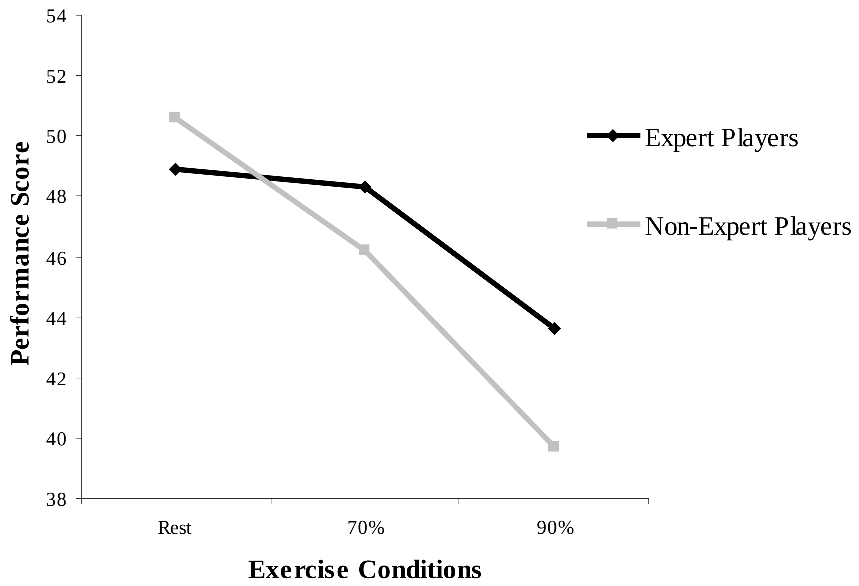
Table 6. Descriptive data for basketball study

Variable	N	Minimum	Maximum	Mean	SD
Score (rest) expert players	10	40.00	58.00	48.90	6.66
Score (70%) expert players	10	38.00	56.00	48.30	5.90
Score (90%) expert players	10	34.00	54.00	43.60	6.70
Score (rest) non-expert players	10	40.00	59.00	50.60	5.52
Score (70%) non-expert players	10	36.00	58.00	46.20	5.92
Score (90%) non-expert players	10	31.00	48.00	39.70	4.37
Change from rest (Δ) to 70% expert players	10	4.00	-6.00	-0.60	3.17

Variable	N	Minimum	Maximum	Mean	SD
Change from rest (Δ) to 90% expert players	10	-1.00	-14.00	-5.30	3.92
Change from rest (Δ) to 70% non-expert players	10	-1.00	-10.00	-4.40	2.76
Change from rest (Δ) to 90% non-expert players	10	-4.00	-17.00	-10.90	13.87

The 3 x 2 mixed ANOVA revealed a highly significant main effect for exercise intensity ($F_{2,\ 36}$ = 44.216, p < 0.001, η^2 = .711). Furthermore, there was a highly significant exercise intensity by level of expertise interaction ($F_{2, 36}$ = 5.252, p = 0.010, η^2 = .226). The between-group differences were not statistically significant however (p = 0.563). The interaction and effects observed here are illustrated in Figure 15. The Shapiro-Wilk test statistic (p > 0.05) revealed that the data were normally distributed. The post hoc analysis revealed that there was a highly significant difference between performance at rest and performance following moderate-intensity exercise (p = 0.001). There was also a highly significant difference between performance at rest and performance following high-intensity exercise (p < 0.001) as well as a highly significant difference between performance following moderate and high-intensity exercise (p < 0.001).

Figure 15. Mean basketball passing performance of expert and non-expert players following rest, moderate and high-intensity exercise



The results indicated that moderate and high-intensity exercise led to a significant decrement in basketball-passing performance compared to resting performance regardless of skill level. Figure 15 also shows that while there were no between-group differences to report, the progression or rate of decline is different in both expert and non-expert players. This was explored by means of the three independent t-tests. The first t-test confirmed that there was a highly significant difference in the rate of decline (Δ) or change in scores of expert and non-expert players from rest to moderate-intensity exercise (p = 0.01). There was also a highly significant difference in the rate of decline of expert and non-expert players from the rest condition to the high-intensity exercise condition (p = 0.005). However, there was no significant difference in the rate of decline from the moderate to high-intensity exercise conditions (p > 0.05) between expert and non-expert players. The Shapiro-Wilk test statistic conducted on the various t-tests here revealed in each case, that the data were normally distributed (all, p > 0.05).

Examination of the descriptive data indicated that within the non-expert players their basketball passing scores at rest, following moderate and high-intensity exercise conditions were 50.60 ± 5.52, 46.20 ± 5.92 and 39.70 ± 4.37 respectively. Thus, a gradual decrease in performance as exercise intensity increased was exhibited in the non-expert players and this is shown in Figure 15. With respect to the expert players, the descriptive data indicate that the mean scores at rest, following moderate and high-intensity exercise conditions were 48.90 ± 6.66, 48.30 ± 5.90 and 43.60 ± 6.70 respectively. Within the expert players therefore, there was little difference between performance at rest and performance following moderate-intensity exercise. Similar to the non-expert players however, there is still a clear decrement in performance following high-intensity exercise as shown in Figure 15. In summary, the results of this study illustrate that overall there was a highly significant exercise intensity effect as well as an exercise intensity by level of expertise interaction. While no between-group differences were found, there were differences in the progression or rate of decline in performance of expert and non-expert players. The rate of deterioration in the performance of the non-expert players appears greater than the expert players.

3.5 Discussion

As has been previously metioned, investigations examining the effects of moderate and intense exercise on skilled performance in basketball are very scant indeed. The fact that no studies have been reported in section 1.8.4, supports the notion that this is a relatively untapped area of research. It is much more difficult therefore, to compare the results of this study to similar studies on basketball. This leaves the researcher with a limited basis for comparing findings.

With respect to the current study, the first notable finding of this investigation was that the mean scores at rest were slightly higher in the non-expert players than the expert basketball players which may be due to motivational factors. Tomporowski and Ellis (1986) suggested that “exercisers” would be highly motivated to perform well under exercise stress. It is plausible also that this was a factor even during the rest trial.

Another explanation may lie in the fact that the test was so basic it did not sufficiently distinguish between the different standard players. To ascertain if the difference at rest was statistically significant, a t-test was conducted but showed that the difference was not significant ($p > 0.05$). It is also important to acknowledge that the exercise intensity by level of expertise interaction may, in part, be due to the differences in the resting scores between the groups.

With respect to the hypotheses stated earlier, the first hypothesis is accepted as basketball passing performances deteriorated significantly following high-intensity exercise, compared to the other two exercise conditions. The post hoc analyses revealed highly significant differences across each of the three intensities with a progressive deterioration in performance as exercise intensity increased. The second hypothesis is rejected however, as the mixed ANOVA revealed no between-group differences. However, it is clear from Figure 15 that there are differences in the rate of decline between expert and non-expert players. The independent t-tests confirmed this. The novice players' rate of decline from rest to moderate intensity was significantly greater than the rate of decline in the expert players. In percentage terms, the non-expert players deteriorated by 12.3% from rest to moderate-intensity exercise compared to an 8.7% decline in the expert players performance. There was also a highly significant ($p = .005$) difference in the rate of decline of expert and non-expert players from the rest condition to the high-intensity exercise condition. Performance deteriorated by 21.5% in the non-expert players compared to a 10.8% decrement in the expert players from rest to high-intensity exercise. Interestingly, there was no significant difference ($p > 0.05$) in the rate of decline from the moderate to high-intensity exercise conditions. It is clear therefore, that despite the lack of between-group differences in the main analysis, there are differences in the performance of the expert and novice players that require further exploration. In sum, the results of the follow-up analyses here show that the deterioration in performance in the non-expert players from rest, to moderate and high-intensity exercise was much steeper than that of the expert players. In study one it was shown that the performance of two semi-professional players who were part of the sample declined very little across the different exercise intensities. The current study again shows that the rate of decline in the performance of the expert players is much less than their non-expert counterparts. Consequently, the findings of the initial investigation suggest that expert players may be capable of maintaining a higher level of play across the different exercise intensities compared to the non-expert counterparts.

Again the results support the idea that high-intensity exercise is accompanied by a decline in performance. Accordingly, while the rate of decline was less in the expert players, there was still a deterioration in their basketball passing performance from rest to the high-intensity exercise condition. The data provide further support for the notion that high-intensity exercise impacts negatively on performance and furthermore, that this decline occurs in both non-expert and expert players alike. The deterioration in performance following high-intensity exercise in both groups supports selected laboratory-based findings (Berger & Smith-Hale, 1991; Al-Nakeeb et al., 2002 & 2003) as well as field-based findings (Davey, Thorpe & Williams, 2002). There are also differences in terms of how expert and non-expert players perform under exercise conditions. This agrees with the findings of Aune, Ingvaldsen and Ettema (2008) who also discerned marked differences in the performance of highly skilled players and recreational players with the highly skilled players maintaining a higher level of performance during fatigue. Figure 15 illustrates that at moderate and high intensities the expert players in this study were able to perform at a higher level than their non-expert counterparts.

The results obtained during this study, are similar to those of McGregor et al. (1999) where ball dribbling performance significantly decreased immediately following fatiguing exercise. A study conducted by Ali and Gant (2007) also found that soccer passing performance declined following fatiguing exercise. In both studies the exercise protocol involved performing the LIST for 90 minutes and so the results need to be interpreted with this in mind. In percentage terms the deterioration from rest to high-intensity exercise in the McGregor et al. (1999) study was 5% and in the Ali and Gant (2007) study was 5.41%. In the basketball study conducted as part of this work the deterioration in performance from rest to high-intensity exercise was much greater at 10.8% in the expert players and 21.5% in the non-expert players. The greater deterioration may be due in part to the fact that the LIST is an intermittent protocol with both aerobic and anaerobic elements, whereas the protocol used in this study was very much a short duration, anaerobic-type protocol. The deterioration in soccer passing performance from rest to high-intensity exercise was 7.91%. Again, this was higher than the deterioration found in past studies by McGregor et al. (1999) and Ali and Gant (2007). It has been highlighted in chapter one that the nature of the exercise task may be fundamental when examining the effects of sub-maximal and maximal exercise effects on performance. It seems in the context of the two studies conducted thus far that the deterioration in performance may be greater when the exercise task is more anaerobic in nature rather than aerobic. This will be examined further in subsequent chapters.

The findings of this research however, are contrary to the findings of McMorris et al. (1994). Although it could be argued that the study conducted by McMorris et al. (1994) most closely resembles the research undertaken here, the findings differ in some respects. McMorris and colleagues found that passing performance following moderate exercise was significantly better than performance at rest. Additionally, they found that performance following moderate and high-intensity exercise did not differ significantly. Consequently, the findings of McMorris et al. (1994) followed trends similar to an inverted-U effect. In the current study however, both non-expert and expert players' passing deteriorated significantly following high-intensity exercise compared to their resting scores. There was also a significant decline in performance from moderate to high-intensity exercise. The results of this study contradict those of McMorris and colleagues and therefore, provide little support for inverted-U theory. The predictions of drive theory are not supported by the findings and instead suggest that the there is a negative relationship between arousal and performance regardless of how well-learned or simple the task is. As with the soccer study, the results are a complete contrast to the predictions of Oxendine (1984) with respect to task complexity. Significantly, the results of the present study may be better explained based on the work of Kahneman (1973) and there is consistency in terms of the two studies conducted thus far. These points will be explored and discussed further in chapter seven.

Trying to unravel the mechanisms underlying the decrement in the performance of both expert and non-expert players is certainly challenging. However, some further points warrant mentioning here. For example, Nideffer (1979) hypothesised that physical arousal associated with exercise leads to a narrowing of attentional focus and according to Easterbrook (1959) task-relevant information can be missed. Other researchers (Salmela & Ndoye, 1986) identify that under high-intensity exercise conditions there is an internalising of attention as the participant focuses on their internal signals of pain and discomfort rather than on the performance task. In combination, this suggests that attention could be inhibited when exercise is maximal. In the basketball study it is possible that divided attention on the part of the participants is one of the primary causes for performance deterioration, particularly at high-intensity exercise levels. For example, information provided by the non-expert basketball players in the debriefing sessions revealed that following high-intensity exercise they felt that the strength / power in their legs was “not there”. This is not unusual and the participants in the soccer study also reported similar feelings. Research by Smilios (1998) has shown that power output declines with fatigue, a conclusion which seems to have been borne out by the results found here. The lack of strength or power expressed by the participants manifested itself through inaccurate passes on the three lower targets particularly (as participants had to squat down to pass the ball). Participants also lost control of the ball on occasions and stepped over the restraining line under high-intensity exercise conditions, all of which decreased the score obtained. Therefore, as with the soccer study the decline in performance on the basketball-passing test could be due directly or indirectly to the inability of the specific muscle groups to cope with the demands of the task. Additionally, the reduction in muscle force here could be due to a decrease in the number of fibres that can be recruited to generate force as fibres already recruited begin to fail (Bangsbo, 1994). The possibility that glycogen was selectively depleted during this intense exercise bout from specific muscle fibres is also plausible and warrants further investigation.

It is also possible that the nature of the exercise task here was more strenuous that players would typically be accustomed to in match situations. In basketball, the format of the game (inclusion of time-outs and free-throws) allow periods of recovery from intense bouts of activity and so the lack of recovery time here may have led to a more pronounced effect on performance. An alternative point here is that following the exercise task, attention may have shifted towards the sensations of distress/pain and it may be this which led to the deterioration in performance. The latter hypothesis will be examined further in subsequent chapters.

Based on the observations conducted by the researcher, it was also evident that the decrement in performance seen in this study in both groups was due in part to the discomfort experienced by the players and a disruption in motor control following exercise of this nature. More specifically, it was clear that some of the non-expert players found it increasingly difficult to stay balanced when passing the ball and moving laterally from one target to the next. Again, this was more problematic following high-intensity exercise. For example, the number of times players incurred penalties for stepping over the passing line increased. Previous investigations have also shown that high-intensity muscular fatigue increases the likelihood of balance problems (Johnston et al., 1998; Vuillerme, Nougier & Teasdale, 2002). Appropriate coordination between postural control and voluntary movement is an essential requirement for accurate movement execution (Vuillerme, Nougier & Teasdale, 2002). This seemed difficult for some of the players following high-intensity exercise. Linked to this is the final observation with respect to the number of times players fumbled the ball across conditions. On occasions it was also evident that the players' perceptual or reactive skills to the ball rebounding off the wall were diminished. For instance, during the resting condition in both groups very few ball handling errors were made. However, following moderate and more commonly high-intensity exercise, the number of errors increased. In the present investigation this was manifest in terms of players not catching the ball cleanly on its rebound from the wall or players fumbling the catch. It seems therefore, that there is a decline in technical skills with increasing exercise levels. This finding is not uncommon in the scientific literature especially following high-intensity exercise or fatigue (Apriantono et al., 2006; Royal et al., 2006).

3.6 Conclusions

The results of this study certainly share some common trends with the results found in the soccer study. The results of the basketball study demonstrated that passing performance deteriorates significantly following high-intensity exercise. In both the football and basketball studies however, there was a negligible difference between performance scores at rest and that following moderate-intensity exercise. With respect to exercise effects and the issue of expertise, this study revealed no significant between group differences. However, further analysis did reveal that the progression or rate of decline with increasing fatigue differs in expert and non-expert players. A more rapid rate of decline in the performance of the non-expert players was demonstrated here. The findings are also suggestive that across moderate and high-intensity exercise levels expert players are capable of maintaining a better level of performance than non-expert players. This will be explored further in the next chapter.

The results of this study again provide little practical support for the predictions of Hull (1943) and Yerkes and Dodson (1908). Similarly, the findings are very much contrary to the view by Oxendine (1984) that when task complexity is low, high levels of arousal are required for optimal performance. In fact, the results found in this experimental study provided a complete contrast to this prediction. However, the findings may be explained by Kahneman's (1973) multidimensional allocation of resources theory. It is possible that the consistency in the performance of the expert players at rest and moderate exercise intensity may be due to the fact that they are capable of allocating sufficient resources to the basketball passing task thereby maintaining a high level of performance. They do not experience the decline in performance therefore, due to this allocation of resources mechanism. Conversely, the deterioration in the performance of the non-expert players may also link to cognitive effort and their inability to allocated sufficient resources to the task to maintain optimal performance. The theories underpinning Kahneman's (1973) work are supported to some degree by the results found in both experimental studies conducted thus far and so this warrants further investigation in subsequent chapters.

4.0 THE EFFECTS OF MODERATE AND HIGH-INTENSITY EXERCISE ON COINCIDENCE ANTICIPATION AMONG EXPERT AND NON-EXPERT GAELIC GAMES PLAYERS

4.1 Introduction

The present chapter describes a study examining the effect of moderate and high-intensity exercise on performance in expert and non-expert Gaelic games players (hurlers). From the preliminary results, in particular those in the previous study, it appears there may be some differences in the performance of expert and non-expert players under exercise conditions. In both groups, a deterioration in performance has been observed following high-intensity or intense exercise conditions compared to resting performance. The basketball study also revealed that the rate of decline is greater in the non-expert players. Moderate-intensity exercise, on the other hand, impacted little on the performance of the soccer passing task but did lead to decrements in basketball passing and so no clear trend has emerged here yet and additional exploration is warranted.

It is also evident from the observations of the researcher and the players' post-testing feedback that the decline in performance is due to a combination of factors. One such factor is the deterioration in technique or technical skill with increasing exercise intensity. According to Thomson (2000) one of the most important reasons why mistakes of a technical nature occur during competition is due to correctness of anticipation. Rothstein and Wughalter (1987) also highlight that the capacity to predict, or the anticipation of coincidence is an important underlying process in the performance of open skills. In study two, impaired anticipation was a feature of the performance of player's particularly following high-intensity exercise. In some instances players did not anticipate the pace of the ball as it returned from the wall. In a number of instances this led to players fumbling the ball, which in turn slowed them down, reduced their fluency moving laterally across the wall and in the end reduced their overall performance score. Poor anticipation of the ball therefore, led to a subsequent spiral of events that reduced overall performance. The current study extends the work conducted thus far, exploring the effects of moderate and high-intensity exercise on coincidence anticipation.

This study once again, evaluated whether exercise effects were the same regardless of level of expertise. The task used in this study however, required attention and included both perceptual and judgmental components and so was more complex than that in study two. Therefore, the claims of Oxendine with respect to task complexity were examined here. This study used a general exercise task (running) as opposed to the more localised or anaerobic-type exercise protocols used so far. The protocols used thus far concentrated on short duration exercise tasks that were more anaerobic than aerobic although the exact contribution of both is not quantified. The rationale for utilising anaerobic-type tasks was linked to the importance and considerable anaerobic component within those sports.

Within Gaelic games, there is a distinct lack of empirical scientific research relating to match demands. The scientific literature on hurling is even more limited (Reilly & Doran, 2001) and so the protocol employed in this study considered the available literature on Gaelic games. Keane, Reilly and Hughes (1993) found that Gaelic football makes most demands on the aerobic system and emphasises technical aspects of game skills. Florida-James and Reilly (1995) found the mean heart rate during competitive games to be 158 ± 11bpm in British-based players. Reilly and Doran (2001) in their review concluded that players are required to run repeatedly with or without the ball and the mean heart rates throughout competitive matches imply a predominance of aerobic metabolism during competition. Reilly and Keane (2002) studied 20 inter-county and 13 club players during competitive Gaelic football games and found the mean heart rate was 169bpm with peak heart rates of 201 ± 16bpm in the inter-county players and 205 ± 10 bpm in the club players. Inter-county (elite) players spend 10.5% of match time at heart rates exceeding 181bpm and 42.5% of time at 161-180bpm, with the remaining time spent at intensities less than 131bpm. Finally, O'Donoghue et al. (2004) found that in hurling 7.5% of match-play involves intermittent high-intensity activity (running, shuffling and game-related play) and 93.5% of time is spent in light-to-moderate aerobic activity (stationary, walking, jogging forwards and backwards). In light of the available literature therefore, the emphasis on repeated running and a high aerobic contribution within the game, it was decided that a more aerobic running protocol would be more appropriate in the case of this investigation.

In brief, Hurling is one of the three national Gaelic games of Ireland and considered to be one of the fastest and most skilful field games in the world (Fahey, Hassett & Ó Brádaigh, 1998). It is a contact team sport (15-a-side), played with a curved metre-long ash stick called a 'hurley' and a small hard leather ball called a 'sliotar' (for more detail, see Fahey, Hassett & Ó Brádaigh, 1998). Hurling is played on a pitch approximately 137 m by 82 m with goalposts at each end. The ball moves rapidly from end to end, with frequent scoring and the ball is rarely out of play. To score, the ball must be hit over or under the crossbar for a point or goal respectively, the latter being equivalent to three points. The ball is struck two-handed on the ground or in the air with a swinging action known as 'the pull'. This is a fundamental skill requiring a fast and powerful swing of the hurley. Players can physically contest possession of the ball with shoulder-to-shoulder charges and so the game encompasses highly physical contact with vigorous efforts. The variety of skills within the game (e.g. striking the ball, blocking and hooking) all need to be performed at high speeds. O'Donoghue et al. (2004) found that the average percentage of time spent in game-related play by each player was just 3.1%. It is fundamental therefore, to use the ball constructively each time possession is gained.

Due to the need for split-second reactions (Magner & Doherty, 1976) coupled with the high physiological demands, high-speed interceptive actions are imperative in hurling and often determine the outcome of matches. Poulton (1957) called the making of interceptive actions, coincidence-anticipation (CAT). Prior research examining the effects of exercise intensity on CAT are also summarised in section 1.8.6. However, these previous studies largely show that exercise intensity neither improves or impairs CAT performance. Past research has been criticised however, because in some past studies the interrelationship between perception and action has been ignored (Shim et al., 2005; Ranganathan & Carlton, 2007). Participants in these studies have responded to the stimulus using varied movements and responses, many of which lack ecological validity. It is imperative therefore, that the interceptive tasks have some ecological validity (Proteau et al., 1989).

Researchers (Bowers & Stratton, 1993; Brady, 1996; Ripoll & Latiri, 1997) support the view that when expertise is addressed, experimental conditions and responses need to consider those required on the field of play. The present study sought to address the paucity of research available on Gaelic games and consider the recommendations of past authors (Savelsbergh et al., 2002) in terms of utilising an interceptive movement typically encountered in the game setting.

4.2 Aims and research hypotheses

In light of the information presented so far, the main aims of this study were two-fold. The first aim was to examine the effect of exercise at a moderate and high-intensity on CAT. The second aim was to examine whether the impact of exercise intensity on CAT was the same in expert and non-expert Gaelic games players. This work used an interceptive action or movement commonly used in competitive games (the “pull”). This movement or action was to be performed with maximum force and velocity, as is required in the sport, thus making the interceptive task and experimental design as ecologically valid as possible. The following research hypotheses are explored in this study:

1) CAT performance will deteriorate significantly following high-intensity exercise, compared to performance at rest and moderate-intensity exercise conditions.
2) There will be a significant difference between the performance of expert and non-expert hurlers across the three exercise conditions.

4.3 Method

4.3.1 Participants

Eleven male expert and nine male non-expert hurlers volunteered to participate in this study. The non-expert hurlers were junior standard hurlers and the expert hurlers were current Warwickshire senior hurlers playing in the All-Ireland Championship Division three. The players were recruited using volunteer and opportunistic sampling methods. The mean age, stature and body mass of the expert hurlers was 23.6 ± 4.4 years, 181.5 ± 5.5 cm, and 80.4 ± 12.6 kg respectively. The mean age, stature and body mass of the non-expert hurlers was 26.4 ± 8.6 years, 178.5 ± 5.2 cm, and 89.5 ± 8.0 kg respectively.

4.3.2 Testing site

All testing was carried out in a 10m x 7m fitness assessment suite where the temperature was regulated and maintained between 17 - 19^{o} C during all tests with comfortable, stable humidity. The temperature was monitored using a digital barometer (Model BA116, Oregon Scientific, China). This room was well-lit and adequate space was available to carry out the testing required.

4.3.3 Experimental design

This study used a mixed factoral design. Each participant provided informed consent and a medical history questionnaire prior to any testing having been being fully informed of the nature and demands of the study. All procedures were reviewed and approved by the Institutional Ethics Committee. During the initial testing session, participants were measured for stature and body mass using standard methods. Each participant was then given ten attempts on the Bassin anticipation timer (Model 35575, Lafayette, USA) to familiarise themselves with the test protocol. Following a brief warm-up, each participant then performed twenty anticipation trials under three conditions: rest, moderate and high-intensity exercise. All testing on the three conditions was counterbalanced.

An incremental running protocol on a motorised treadmill (Woodway, GmbH D-79576, Germany) was used to develop moderate and high-intensity exercise states. The protocol started at a running speed of 6, 7 or 8 km/hr dependent on the fitness level of the participant. Fitness level was determined by the investigator from information provided by the participant in advance of the testing relating to the frequency, intensity, time and type of training they were engaged in. The gradient remained at 3% throughout the protocol. The workload was then increased 1 km/hr every 30 seconds until the desired intensity was reached as determined by 70% or 90% HRR. HRR was calculated using Karvonen method (Karvonen, Kentala & Mustala, 1957). As an example, 90% HRR is calculated as follows:

Target Heart Rate (THR) $_{90\%}$ = 90% of Heart rate Reserve

$THR_{90\%} = HR_{rest} + 0.90\,(HR_{max} - HR_{rest})$

Resting heart rate (HR_{rest}) was obtained from each participant before testing commenced by getting them to sit down for 10-15 minutes, wearing a heart rate monitor (Polar Accurex, Bodycare, Finland) in a quiet room devoid of visual or auditory distractions. Maximum heart rate (HR_{max}) was estimated at 220 minus the participants' age. Throughout the testing procedures, HRR was monitored using heart rate monitors and the mean values during each of the three conditions (rest, 70% and 90% HRR) were 79.60 ± 7.18 bpm, 176.1 ± 9.30 bpm and 188.15 ± 7.41 bpm, respectively.

4.3.4 Borg's (1970) Rating of Perceived Exertion (RPE) Scale

Despite the wide use of heart rate in studies of this nature, Fernandez, Mendez-Villanueva and Pluim (2006) have noted that heart rate alone may not be the best indicator of stress intensity due to the fact that heart rate does not always reflect VO_2 variations. In addition, it is well known that heart rate responses can be affected by a host of other factors including thermal stress. Therefore, a second measure is often used in research of this nature that serves as an adjunct to the monitoring of heart rate.

RPE is a valid index of exercise intensity owing to its association with more objective physiological markers, including heart rate and oxygen uptake (Robertson & Noble, 1997). It provides the researcher with a subjective indicator of intensity of effort, strain, discomfort and/or fatigue that is experienced during physical exercise (Robertson & Noble, 1997). The validity and reliability of the scale as an indicator of global internal load or physical stress has been confirmed (Garhart et al., 2002; Impellizzeri et al., 2004; Garcin & Billat, 2001; Novas, Rowbottom & Jenkins, 2003; Fernandez et al., 2005) but also questioned (Lamb, Eston & Corns, 1999; Hartshorn & Lamb, 2004). In the context of this investigation, however, Borg's (1970) RPE scale was used simply as an adjunct to the monitoring of heart rate.

The Borg (1970) scale consists of 15 numbers with verbal anchors placed at the location appropriate to their quantitive meaning: from 6, corresponding to “the effort is very, very easy” to 20, corresponding to “the effort is very, very hard”. Participants were required to reach an RPE of 15 for moderate-intensity and 18 for high-intensity exercise. Once the desired level of intensity was reached, as determined using both measures (HRR and RPE) simultaneously, the participants were then required to maintain this intensity for an additional minute. The mean RPE values following the additional minute were 15.95 ± 0.95 and 19.05 ± 0.51 for the moderate and high-intensity exercise conditions respectively. Both methods and criteria were chosen in order to ensure that participants were truly at the desired exercise intensity. The time taken to reach the moderate and high-intensity exercise intensities was 5.55 ± 0.84 and 7.20 ± 0.80 minutes respectively. Immediately following this additional minute, participants performed the twenty CAT trials.

Once more, the rationale for the methods is based on similar points raised to date:

(1) Again the protocol considers the recommendations of Lewis and Fulco (1998) as well as Åstrand et al. (2003).

(2) This method of inducing moderate and high-intensity exercise states enabled the investigators to account for the fitness levels of each individual participant as it factors in resting heart rate which provides an indication of fitness level.

(3) The criterion task (CAT using the "pull" action) includes the dynamic use of both lower and upper body muscles and therefore a more general exercise task is preferable.

(4) The previous work used localised or anaerobic tasks due to the fact that reviews of the sports suggested that anaerobic type work was significantly important in terms of match demands. The scientific literature pertaining to Gaelic games is much more limited but points to a more significant aerobic running component (Keane, Reilly & Hughes, 1993; Reilly & Doran, 2001; Reilly & Keane, 2002; O'Donoghue et al., 2004).

4.3.5 Bassin anticipation timer

The Bassin anticipation timer was set-up in close proximity to the treadmill (Figure 16). This minimised any delay from when the desired exercise intensity was reached to performance on the anticipation timer. It ensured performance was conducted at the correct exercise intensity. The total time to complete all twenty trials was on average thirty seconds. Again, this was crucial to the experimental design so as to avoid potential recovery effects.

Figure 16. Set-up of testing lab for the hurling study

Three sections of runway (224cm) with the system's LED lights facing the participant were used with an infrared photoelectric cell mounted directly over the target light as shown in Figure 17. The runway sections were mounted on tripods with the lights 87 cm from the floor. None of the lights on the runway were blanked and the target light was light number 13 on the third runway. The sequentially-lighted LED lamps were illuminated in a linear pattern and were designed to give the appearance of a moving stimulus coming toward the participant. The start and ending speeds remained constant at 5mph for all trials. Cue delay (visual warning system) was set to random on the timer with a minimum delay of one second and maximum delay of two seconds. This reduced the likelihood that the participant could internally time the trial. A marker was placed on the floor directly in front of the target light 150cm from the runway. Participants were required to place one foot on this marker so as to standardise the position of the participant in relation to the testing equipment (Figure 17). For each trial the signal was initiated by the researcher. In terms of performance, the CAT scores were recorded in milliseconds as well as whether the response was early (assigned a negative sign) or late (assigned a positive sign). Using alternating pulls, 20 trials were completed in total. The time taken to complete all 20 trials was approximately 30 seconds.

Figure 17. Set-up of the Bassin anticipation timer

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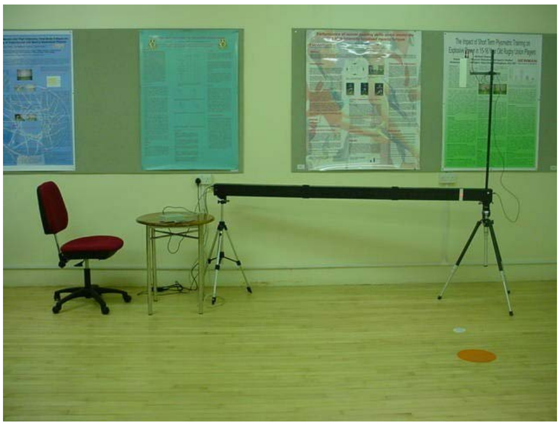

4.3.6 The swing or 'pull' action

To simulate hitting a sliotar, participants swung the hurley or "pulled" using a continuous swing at full speed through the photo-electric beam as close to the arrival time of the stimulus at the target location as possible. Immediately following each of the three counterbalanced conditions (rest, 70% HRR and 90% HRR), participants performed twenty trials on the anticipation timer. For the first trial, participants were required to pull with their dominant side (Figure 18), for the next trial they were then required to pull with their non-dominant side (Figure 19) and alternated in this manner until a total of twenty trials had been completed. The justification for the alternate pulls is that within competitive games, players have to swing the hurley or pull with both their dominant and non-dominant sides. The speed of the game is such that players are not always afforded the time to pull with their dominant side. Hence, this was considered an important element in the experimental design.

Figure 18. Participant performing the dominant swing action

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Figure 19. Participant performing the non-dominant swing action

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4.3.7 Statistical analysis

Each participant's raw scores were firstly summarised into three error scores as a means of generating the dependent variables. The dependent measures were constant error (CE) which is the temporal interval (in milliseconds) between the arrival of the visual stimulus and the end of the participant's motor response. It represents the mean response of the participants and the direction of error: early or late (Schmidt, 1982). Variable error (VE) is the participant's standard deviation from his/her mean response; this represents the variability or inconsistency of responses. VE represents the standard deviation from the mean and so all the values are positive which can sometimes lead to skewed data. To correct for this skewness, the data were log-transformed so that the positive skew in the data was overcome. Log-transforming such data has been shown to overcome skewness in past work (Winer, 1971). Lastly, absolute error (AE) was calculated by taking the absolute value of each raw score disregarding whether the response was early or late. According to Schutz (1977) AE combines both CE and VE to reflect the overall amount of performance error.

The descriptive analysis of data again explored measures of central tendency (e.g. mean values) and dispersion (e.g. standard deviation) using the analysis of descriptive statistics function in SPSS. The descriptive data for the mean of the 20 trials, across each exercise intensity are presented in Table 7. The raw data are presented in Appendix XXII. The effect of exercise on CE, logVE and AE was analysed using separate 3 (exercise intensities) x 20 (trials) x 2 (levels of expertise) mixed ANOVAs. For each analysis the within-subject factors were exercise levels and trials. The between-subjects factor was level of expertise. In the case of this study, the average of the 20 trials was not used and instead it was decided to include trials as a separate within-subject factor. The nature of the output obtained from the Bassin Anticipation Timer allowed for this as individual performance scores after each trial are provided instantly. These were recorded so the 20 trials were included as a within-group factor to explore whether there are changes or trends in performance over the course of the 20 trials at the different intensity levels. Because all treatment conditions were planned, a pairwise least significant difference post hoc procedure was used in the case of significant F scores. The residuals of the 3 x 20 x 2 mixed ANOVAs were again checked for normality using the Shapiro-Wilk test statistic. Homogeneity of variance was evaluated using Mauchly's test of sphericity and when violated, the Greenhouse-Geisser adjustment was used. SPSS Version 17.0 (SPSS Inc., Chicago, IL) was used for all statistical calculations. The level of significance was set at 0.05. The results of the analyses are presented in full in Tables 8, 9 and 10 (Appendix VIII).

4.4 Results

Table 7. Descriptive data for hurling study

Group	Error	Rest	Moderate-exercise	High-intensity Exercise
Non-Experts	Absolute Error	0.053 ± 0.03	0.043 ± 0.03	0.050 ± 0.04
	Constant Error	0.001 ± 0.06	-0.002 ± 0.05	0.002 ± 0.06
	Variable Error	0.049 ± 0.03	0.043 ± 0.03	0.046 ± 0.04
Experts	Absolute Error	0.033 ± 0.03	0.040 ± 0.03	0.036 ± 0.03
	Constant Error	-0.004 ± 0.04	-0.003 ± 0.04	-0.007 ± 0.05
	Variable Error	0.036 ± 0.07	0.042 ± 0.07	0.035 ± 0.03

Mean ± SD values (20 trials combined) all reported in seconds

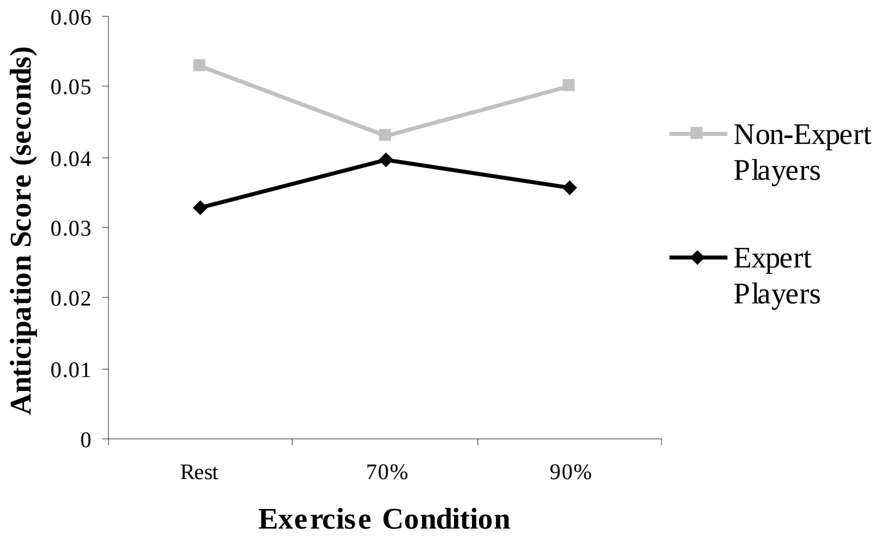
4.4.1 Absolute error

The 3 (exercise intensities) x 20 (trials) x 2 (levels of expertise) mixed ANOVA on the AE error scores indicated that there was no main effect for exercise intensity ($p > 0.05$). However, a significant exercise intensity by expertise interaction was found

($F_{2, 36}$ = 3.839, p = 0.031, η^2 = 0.176), the nature of which is presented in Figure 20. Highly significant between-group differences ($F_{1, 18}$ = 19.437, p < 0.001, η^2 = 0.519) were also found showing that the non-expert hurlers had higher AE scores than the expert players across all exercise intensities. A t-test was also conducted to explore whether the difference between the expert and non-expert players at rest was statistically significant. The results of the t-test confirmed this ($t_{(398)}$ = -6.398, p < 0.001) to be the case.

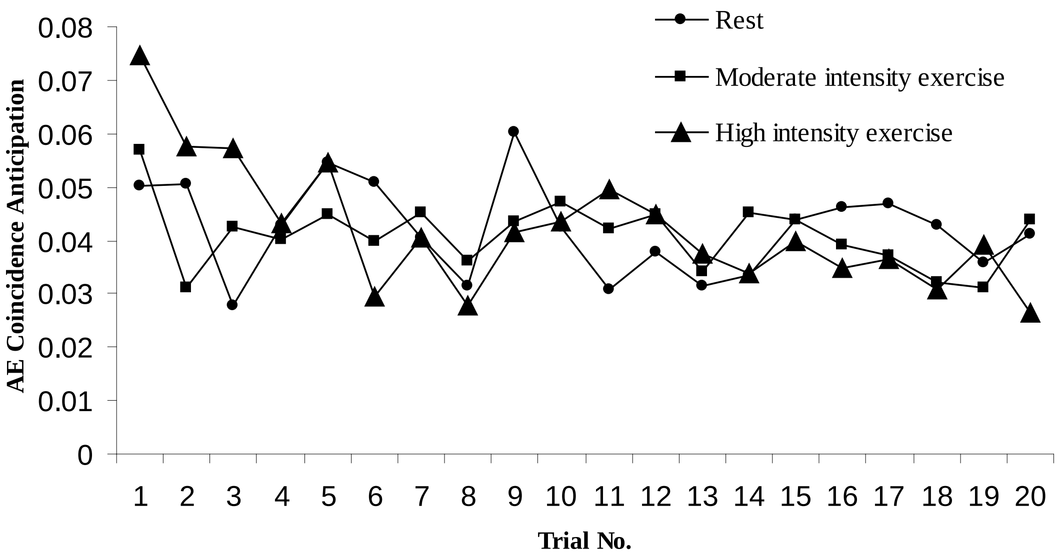
With respect to the non-experts, additional analyses revealed there was a significant exercise intensity effect (p = .016, η^2 = 0.167). This difference was evident between performance at rest and performance following moderate-intensity exercise (p = 0.019). It is clear from Figure 20 that the performance of the non-expert players improved following exercise at a moderate-intensity, with no other differences being evident. With the expert players additional analyses revealed no differences across the three exercise intensities (p > 0.05).

Figure 20. Mean AE scores of expert and non-expert hurlers following rest, moderate and high-intensity exercise



Differences and interactions on a trial-by-trial basis were also examined and the results demonstrate that again there was a highly significant trials effect ($F_{2,\ 38} = 2.473$, $p = 0.001$, $\eta^2 = 0.121$) as well as an exercise intensity by trials interaction ($F_{2,\ 38} = 1.624$, $p = 0.011$, $\eta^2 = 0.083$). This is illustrated in Figure 21. The results of these analyses are presented in full in Tables 8 and 9 (Appendix VIII).

Figure 21. AE trial by exercise intensity interaction



4.4.2 Log variable error

The 3 (exercise intensities) x 20 (trials) x 2 (levels of expertise) mixed ANOVA on the log-transformed VE scores showed a similar trend to the results reported for the absolute error scores and when plotted, showed the same trends as Figure 20. Once more, there was no main effect for exercise intensity ($p > 0.05$) but there was an exercise intensity by level of expertise interaction, which was approaching significance ($F_{2,36} = 3.259$, $p = 0.05$, $\eta^2 = 0.153$). The results again demonstrated highly significant between-group differences ($F_{1,18} = 13.095$, $p = 0.002$, $\eta^2 = 0.421$). Further within-group analyses identified that there were no differences across the 3 exercise intensities ($p > 0.05$) in the expert players. However, in the non-experts there was a significant exercise intensity effect ($p = 0.028$, $\eta^2 = 0.361$). The non-expert players' data revealed a significant difference ($p = 0.018$) between performance at rest and performance following moderate-intensity exercise, thus mirroring the improvement at moderate-intensity found for the AE data. The results of these analyses are presented in full in Tables 10 and 11 (Appendix VIII).

4.4.3 Constant error

The 3 (exercise intensities) x 20 (trials) x 2 (levels of expertise) mixed ANOVA on the constant error scores indicated that there were no between or within-subject differences (all $p > 0.05$). The results of the CE analyses are presented in full in Table 12 (Appendix VIII).

4.5 Discussion

The capacity to predict, or the anticipation of coincidence is an important underlying process contributing to success in sports wherein predicting the arrival of a moving object is important (Molstad et al., 1994). CAT is particularly important in externally-paced sports which involve uncertainty (Singer et al., 1996). Anticipation has also been cited as a critical component of expert performance in fastball sports (McRobert et al., 2007). Soccer, basketball and hurling are all externally-paced sports involving uncertainly and hurling is undoubtedly a fastball sport. The results of this study are pertinent therefore, and have implications for performance in those sports studied thus far.

The evaluation of CAT timing behaviour is achieved by means of three variables (CE, VE and AE) and so, for consistency, the analyses conducted on each of these variables will be discussed separately. Given that AE combines both CE and VE to reflect the overall amount of performance error (Schutz, 1977) there will be a greater focus on this in the following section. The first notable finding in terms of the AE analyses was the absence of a main exercise intensity effect but there was an exercise intensity by expertise interaction (p = 0.031). In an effort to explore this interaction further, between-group differences were firstly examined. The mixed ANOVA revealed that there were highly significant between-group differences ($p < .001$). Figure 20 supports this and illustrates that the expert players performed better across all exercise intensities compared to the non-expert players. This finding is not consistent with between-group analyses in the basketball study where no between-group effect was found. However, despite the lack of statistically significant between-group effects in that study, the expert players nevertheless performed better than the novice players under moderate and high-intensity exercise conditions. There is some consistency therefore in the findings of the basketball study and the present study in that the expert players maintain a higher level of performance across moderate and high-intensity exercise conditions. In study two while the expert players also revealed a similar trend (i.e. better performance than the non-expert players at moderate and high intensities) the difference was not statistically significant. Janelle and Hillman (2003) hypothesised that because experts are more capable of demonstrating superior performances than non-experts, they may also be capable of dealing with affective states more appropriately. The results thus far, provide only partial support for this claim.

A t-test conducted on the AE scores also confirmed that there was a highly significant ($p < .001$) difference in the scores of experts and non-experts at rest. This is interesting as past research also points to the fact that elite athletes anticipate movements more accurately in a variety of fastball games (Abernethy & Burgess-Limerick, 1992). Research on CAT however, has provided conflicting results with respect to expert-novice differences. Some studies showed experts to be more accurate and less variable than novices (Isaacs & Finch, 1983; Chen et al., 1993; Tenenbaum, Sar-El & Bar-Eli, 2000) while others found no differences (Dunham, 1989; Etnyre et al., 1992; Millslagle, 2000). Expert players however, are generally more accurate than novices in CAT actions when the conditions are similar to those in their field of practice (Benguigui & Ripoll, 1998). Past research (Bowers & Stratton, 1993; Brady, 1996;

Ripoll & Latiri, 1997; Tenenbaum, Sar-El & Bar-Eli, 2000) as well as the present results also confirm this. The importance of utilising interceptive movements encountered in game settings is also reinforced here. From an applied perspective, it is important given the field-based nature of this work so far to underscore the validity of a laboratory technique such as the Bassin anticipation timer for evaluating coincident timing. This point has also been raised previously by Ripoll and Latiri (1997). Accordingly, the current research provides some evidence that the system has construct validity particularly when the interceptive task is sport-specific or ecologically valid.

The within-group analyses on the experts' AE revealed no significant differences in performance across exercise intensities ($p > 0.05$) thereby showing that among the expert players, their performances remained consistent across exercise intensities. The findings therefore, mirror those of Al-Nakeeb et al. (2005) who similarly found no changes in AE in highly skilled performers across different fatigue levels. In the study by Al-Nakeeb et al. (2005) a press-button response was used and no changes in performance were found across similar exercise / fatigue intensities. The authors concluded that future research needed to use tasks with greater sensory-motor demands. The CAT task employed in this study imposed greater demands on both the sensory-motor and motor phases respectively. Despite this, no changes in AE were found in the expert players, thereby providing further support for the findings of Al-Nakeeb and colleagues as well as many of the findings of Fleury and colleagues. The results however, contradict those of Isaacs and Pohlman (1991) where AE significantly deteriorated while cycling at VO_2 peak. In the current study, the nature of the fatiguing task and performance task differed significantly to those used by Isaacs and Pohlman (1991) and so differences in findings need to be considered in light of these methodological differences.

Again, trying to unravel the mechanisms underlying these results is challenging. However, Tyldesley and Whiting (1975) point out that there is an inordinate degree of consistency in the movement patterns displayed by skilled sports performers. There is evidence of this in the performance of the experts across all exercise intensities. The consistency of the experts may also relate to the notion by Meeuwsen, Goode and

Goggin (1995) that regardless of the complex sensory and motor processes involved in a CAT task, humans perform such tasks generally without much difficulty. The fact that the task was also coupled may influence the findings here. Tresilian (2005) suggested that the nature of perceptuomotor coupling becomes more specific with practice. In this case, the high accuracy among expert players could be the result of a specific ability to more accurately synchronise their responses to the arrival of the moving simulus on the timer (Ranganathan & Carlton, 2007). Furthermore, Milner and Goodale (1995) proposed that there are two separate neurophysiological streams involved in visuomotor responding: (a) a ventral stream that is responsible for the identification and classification of the visual stimuli and (b) a dorsal stream that is responsible for the control of motor actions on the basis of the visual stimuli. Thus, the use of a coupled perception-action environment /response primarily involves the dorsal stream. With respect to coupled environments, Farrow and Abernethy (2003) suggest that there may be specialised neural circuits for processing stimulus/ball flight information. These aspects of perception-action coupling require further research using ecologically valid tasks but this study at least, revealed that the interceptive task, despite placing large sensory-motor and motor demands on the expert players is so common and familiar to them, that even under intense exercise intensity they can still co-ordinate and synchronise the pull action to the arrival of the moving stimulus. Performance therefore, remains optimal.

Another point that warrants consideration here is the possibility that the metabolic and perceptual systems involved here are in fact independent. This has been put forward in a number of past studies relating to this topic (Bard & Fleury, 1978; Fleury et al., 1981). Fleury and colleagues suggested that physical fatigue seems to leave the afferent pathways involved in this type of information-processing activity unimpaired, so again this may be a plausible explanation for the lack of difference found within the expert hurlers' performance across the moderate and intense exercise intensities. The within-group analyses conducted on the non-expert players' AE scores however, showed different trends. Firstly, there was a highly significant (p = 0.016) improvement in their performance following moderate-intensity exercise compared to their resting scores. This is the first study therefore to show a significant improvement following moderate-intensity exercise relative to the resting performance. The task is also more complex than the finger depression or voice response tasks used in past literature to measure CAT. The within-group analyses for the non-expert and expert players therefore, show some common trends such as the lack of difference between performance at rest and that following high-intensity exercise. This finding is also consistent with inverted-U theory. However, the significant improvement in performance following moderate-exercise in the non-experts is not consistent with the results of the experts. This improvement following moderate-exercise is also inconsistent with previous research on this topic (Isaacs & Pohlman, 1991; Thomson, 2000; Al-Nakeeb et al., 2005; Al-Nakeeb & Lyons, 2007). The results of the non-experts in the current investigation therefore, offer a complete contrast to the latter studies highlighted here but are consistent with trends proposed by Yerkes and Dodson (1908).

The final point that warrants mentioning with respect to the AE data is the significant (p = 0.011) exercise intensity by trials interaction. This is illustrated in Figure 21. As can be clearly seen from this graph, the biggest decrement was evident during the first CAT trial immediately following high-intensity exercise and the best performance trial was the last trial. The values gently taper therefore, with the worst performance score (trial 1) being performed immediately on exercise cessation and the best trial being the one performed last (trial 20). The fact that the worst performance score was that immediately following exercise cessation is significant in an applied sense because in sport, we often get just one attempt. The findings here also emphasise the point by Davranche and Audiffren (2004) that the timing of the performance task is a decisive factor because the effects of exercise may only last for a very short period of time. Smilios (1998) also observed rapid recovery from exercise and the current study provides evidence that this is in fact the case. The twenty trials were performed immediately post-exercise and all trials were completed within approximately thirty seconds. Nonetheless, over the course of the trials, there is evidence in Figure 21 that some recovery may be taking place on the last trial(s). Furthermore, it may be that a degree of learning also takes place over the 20 trials. The rationale to keep the performance task time in this research as short as possible is vindicated somewhat by Figure 21 and the trend that is presented over the time course of the 20 trials.

With respect to the logVE data, the results and interactions found were very consistent with the AE results. The exercise by expertise level interaction was approaching significance ($p = 0.05$) but the nature of the interaction was the same as that discussed previously and presented in Figure 20. Highly significant ($p = .002$) between-group differences were again found, consistent with the AE analyses. Further within-group analyses on the expert and non-expert players' logVE data again showed the same findings. There were no differences across exercise intensities ($p > 0.05$) in the expert players and the non-expert players improved significantly ($p = 0.028$) following moderate-intensity exercise. The results and interactions found therefore, in terms of the global measure of timing behaviour (AE) and variability of error (logVE) are very consistent in this study.

With respect to the CE data analyses, no between or within-group differences ($p > 0.05$) were found highlighting that any changes in CAT behaviour are not evident in terms of the direction of error (CE). This finding is consistent with the research conducted by Al-Nakeeb and colleagues (2005 & 2007) where again exercise at these intensities had no impact on CE. However, earlier research on this topic has indicated significant improvement in some cases (Fleury, Bard & Carrière, 1981; Fleury & Bard, 1987) and in other instances, significant deterioration (Isaacs & Pohlman, 1991) following exercise/fatigue. It should be pointed out, nevertheless, that in many of these past studies, the interceptive actions, fatiguing tasks and timing of CAT performance trials differed greatly from the present study. The CAT task in the present study is significantly different to any others reported in the scientific literature and so critical evaluation of the current findings with past research is more intricate.

Trying to put the results found here in a theoretical framework is more complex given the number of variables (types of error, exercise intensities and levels of expertise). Greater focus therefore, will be placed on the analyses of the AE because it combines CE and VE to reflect overall performance error (Schutz, 1977). In view of this, what does seem clear from the data gathered is that the performance of the expert players across exercise intensities refutes all the classic theories of arousal proposed by Yerkes and Dodson (1908), Hull (1943) and Kahneman (1973). The results found are also contrary to the predictions of Oxendine (1984) with respect to task complexity but do support some of the predictions put forth in processing efficiency theory (Eysenck, 1992; Eysenck & Calvo, 1992). In this study, both groups of players could be regarded as high motivated due to their volunteer status, the fact that they all are actively engaged in training and playing competitive matches in what is essentially a minority sport. Their performance in this study concurs with the results found in the two expert (semi-professional) players in the soccer study where, again, little or no change in performance across moderate and high-intensity exercise levels was evident.

Within the performance of the non-expert players, the results found were different to the expert players as the performance of the non-experts improved significantly following moderate-intensity exercise, a trend consistent with inverted-U theory and drive theory. This is also consistent with the results found in the soccer study although in that study the improvement was not a statistically significant one. The results of the non-expert players are inconsistent with the suppositions of Hull (1943) and Oxendine (1984). With respect to the between-group differences, again the experts demonstrated significantly better CAT scores than the non-experts and they maintained a higher level of performance across all exercise intensities which is consistent with those findings in the basketball study.

4.6 Conclusions

In sports such as hurling, complex CAT actions and motor skills are performed under varying levels of exercise. Players frequently have to perform such tasks while processing other information from an open, dynamic and ever-changing environment. The effect of exercise on perceptual motor performance, therefore, is of great interest to players, coaches, trainers and sport scientists. The results of this study revealed that there was no deterioration in the performance of the expert and novice players across exercise intensities and so the first hypothesis of a decline in performance following high-intensity exercise is rejected here. The lack of performance changes under exercise conditions is again consistent with a very similar study conducted by Al-

Nakeeb and Lyons (2007) where no changes in AE were found in highly skilled performers across similar intensity levels. This consistency may relate to the point by Fleury et al. (1981) that physical fatigue does not impair the afferent pathways involved in this type of information-processing activity. It may also support the argument that general forms of exercise do not impair performance as much as localised forms of exercise.

With the non-expert players, their results are indicative of an inverted-U effect. In the present study, the improvement following moderate-intensity exercise was also statistically significant and so supports the suppositions of Yerkes and Dodson (1908). Finally, the between-group analyses here revealed highly significant differences were found when the expert and novice player's performances were compared across the three intensities. The expert players in this study at least were capable of maintaining a higher level of performance than their non-expert counterparts under different exercise intensity conditions. Between-group differences have not been consistently found across the studies to date but the research hypothesis that the expert players will perform at a higher level than the non-expert players was accepted here. Further research is warranted before drawing more definitive conclusions. This is the first study however, where a statistically significant between-group (expertise) effect was found and so there is a need for follow-up investigations of this.

5.0 THE EFFECTS OF MODERATE AND HIGH-INTENSITY EXERCISE ON ATTENTION

5.1 Introduction

The work conducted thus far has examined the effect of moderate and high-intensity exercise on the performance of sports skills in expert and non-expert players. The research then extended to examine CAT using a commonly-used sport-specific interceptive task in a chosen sport (hurling). It is clear now that there are a number of emerging trends in the findings. Conversely, there are also some inconsistent findings which will be discussed in more detail in chapter seven. One aspect of performance which is fundamental to the theories of arousal is that of attention. The present chapter describes a small-scale study that examined attention at rest, following moderate and high-intensity exercise conditions.

Attentional focus is defined as the ability to focus despite irrelevant environmental disturbances (Nougier, Stein & Bonnel, 1991). In sport, the importance of appropriately directing and sustaining attention during a sporting competition has been confirmed by athletes for years. However, the task of attending appropriately in sport can be challenging and taxing especially if required under different levels of exertion or exercise. Within competitive sport situations, internal as well as external distractors abound and may potentially influence one's attentional state at any time. Internal factors include one's own thoughts or subjective feelings of exercise and external factors are those such as crowd noise or temperature (Moran, 1996). What is fundamentally important, however, is that under conditions of depleted resources (i.e. anxiety or fatigue), distractors compete with relevant cues for already diminished assets, resulting in the allocation of fewer resources for task performance (Moran, 1996). Consequently, the ability to orient attention appropriately may be compromised. Wegner (1994) takes this argument further adding that in conditions of high emotionality (e.g. high pressure situations) or depleted cognitive resources (e.g. intense exercise or fatigue states), individuals express a greater tendency to redirect attention away from the central task and to irrelevant and potentially detrimental stimuli. The idea that fatigue states are associated with reduced attentional capacity and increased distractibility has been reinforced more recently by Desmond and Hancock (2001).

The present study was designed to examine the effects of moderate and high-intensity exercise on attention specifically. In section 1.8.5 selected studies were outlined examining the effects of exercise and fatigue on attention. In order to avoid repetition, these will not be emphasised here again but generally the findings of these studies are discrepant. Some studies (McGregor et al., 1999; Thomson, 2000; Al-Nakeeb & Lyons, 2007) found no effects of fatiguing exercise on attention while other studies (Hogervorst et al., 1996; Miles & Roberts, 1998) showed that high-intensity exercise more specifically, compromised one's attentional state. Reilly (1997) believes that lapses in concentration may partly explain why, in soccer, the distribution of goals scored during football matches shows a bias towards more goals being scored towards the end of the game. Given the importance of this concept to performance in sport and the underlying importance of this concept in terms of the various theories of arousal, this study may provide some insight into the results collated thus far.

5.2 Aims and research hypotheses

The main aim of this study was to examine the effect of moderate and high-intensity exercise on attention as measured by the Stroop (1935) colour-word test. The following research hypotheses will be explored in this study:

1) There will be a significant deterioration in Stroop test performance (attention) following high-intensity exercise.
2) There will be no difference in attention following moderate intensity exercise compared to resting performance.

5.3 Method

5.3.1 Participants

Twelve physically active male college students participated in this study. The participants were recruited using volunteer and opportunistic sampling methods. Their mean age, stature and body mass was 21.25 ± 0.59 yrs, 180.91 ± 1.22 cm, and 80.86 ± 3.65 kg respectively.

5.3.2 Testing site

All testing was carried out in a 10m x 7m fitness assessment suite where the temperature was regulated and maintained between 17 - 19^{o} C during all tests. The temperature was monitored using a digital barometer (Model BA116, Oregon Scientific, China).

5.3.3 Experimental design

This study again used a repeated measures design. Each participant provided informed consent and a medical history questionnaire after being fully informed of the nature and demands of the study. All procedures were reviewed and approved by the Institutional Ethics Committee. Subsequent to the measurement of stature and body mass, participants performed the Stroop Test under three conditions: rest, moderate and high-intensity exercise. All testing on the three conditions was counterbalanced.

An incremental running protocol on a motorised treadmill (Woodway, GmbH D-79576, Germany) was used to develop moderate and high-intensity exercise states. The protocol started at a running speed of 6, 7 or 8 km/hr dependent on the fitness level of the participant. Fitness level was determined by the investigator from information provided by the participant in advance of the testing relating to the frequency, intensity, time and type of training they were engaged in. The gradient remained at 3% throughout the protocol. The workload was then increased 1 km/hr every 30 seconds until the desired intensity was reached as determined by 70% or 90% HRR. HRR was calculated using Karvonen method (Karvonen, Kentala & Mustala, 1957).

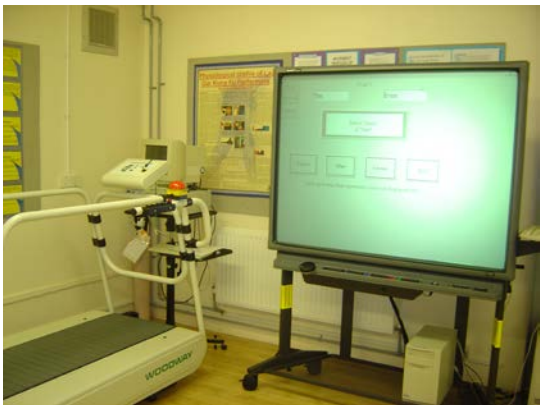
Resting heart rate (HR_{rest}) was obtained from each participant before testing commenced by getting them to sit down for 10-15 minutes, wearing a heart rate monitor (Polar Accurex, Bodycare, Finland) in a quiet room devoid of visual or auditory distractions. Maximum heart rate (HR_{max}) was estimated at 220 minus the participants' age. Borg's (1970) RPE scale was again used as an adjunct to monitoring of heart-rate. The rationale for the methods used here is consistent with those points outlined in the previous three studies conducted and so will not be repeated here. The desired exercise level (as indicated by both HRR and RPE), when achieved, was maintained for a further minute to ensure that participants were truly at the desired intensity level.

5.3.4 The Stroop (1935) Colour-Word Test

While Stroop (1935) was originally concerned with how best to explain interference, over three hundred articles published to date have used the test as a measure of attention (Macleod, 1991). Reliability and validity have been reported by various authors (Santos & Montgomery, 1962; Jensen, 1965). The test demonstrates good reliability and validity overall (MacLeod, 1991). In the original Stroop test, participants were asked to name the colour of ink of each word in a list. When the words in the list are the names of the ink colours, but the word and ink colour do not match (for example, the word 'green' may be written in red ink) the task becomes more difficult.

For the purposes of this research, an electronic version of the Stroop Test (Psytek, UK) was set up on a rear projection whiteboard (SmartBoard 2000i, SMART Technologies, Canada) in close proximity to the treadmill as shown in Figure 22.

Figure 22. Experimental set-up of the Stroop Test



This image has been removed for data protection reasons. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University

Four colours were used in this experiment, red, blue, green and yellow. The projection whiteboard presented a random sequence of colour names, one at a time, in random colours of ink. The participants had to respond by touching (with their dominant hand) one of the four buttons on the screen that represents the colour of the word in front of them as shown in Figure 23. When the correct response was made another word appeared on the screen and the test continued in this way until a total of 24 words (or trials) were conducted, after which the test stopped automatically. The completion time comprised the total time taken to repond to all of the 24 words. This was recorded electronically to within one hundredth of a second and appeared on the screen at the end of the test. The total number of incorrect responses was also recorded.

Figure 23. Participant performing the Stroop Test

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The average time to complete the Stroop Test was 20-25 seconds. During the initial testing session, each participant was given one attempt on the Stroop Test for the purpose of familiarisation with the test protocol. Participants were given specific instructions during each of the three conditions (rest, moderate and high-intensity exercise) to complete the test as quickly as possible without making errors but even if they did make an error, they were informed to continue on to the best of their capability.

5.3.5 Statistical analysis

The preliminary analysis explored measures of central tendency (e.g. mean values) and dispersion (e.g. standard deviation) using the analysis of descriptive statistics function in SPSS. The descriptive data are presented in Table 13. The raw data are presented in Appendix XXII. ANOVA with repeated measures was carried out on the recorded Stroop performance times and the number of errors. Because all treatment conditions were planned, a pairwise least significant difference post hoc procedure was used in the case of significant F scores. With each analysis, the residuals of the repeated measures ANOVA were checked for normality using the Shapiro-Wilk test statistic. Homogeneity of variance was evaluated using Mauchly’s test of sphericity and when violated, the Greenhouse-Geisser adjustment was used. SPSS Version 17.0 (SPSS Inc., Chicago, IL) was used for all statistical calculations. The level of significance was set at 0.05.

5.4 Results

The repeated measures ANOVA identified a significant main effect for exercise intensity ($F_{2, 22} = 4.134$, $p = 0.030$, $\eta^2 = .273$). Using the LSD adjustment, results indicated that there was a highly significant difference ($p = 0.003$) between performance on the Stroop Test at rest compared to performance following high-intensity exercise. Furthermore, there was a significant difference ($p = 0.032$) between performance following moderate-intensity exercise compared to performance following high-intensity exercise. There was no difference between performance at rest and that following moderate-intensity exercise ($p > 0.05$).

Table 13. Descriptive data (mean ± SD) for the Stroop study

Variable	**Rest**	**70% HRR**	**90% HRR**
Time (seconds)	22.16 ± 2.56	22.12 ± 2.47	23.34 ± 2.74
Errors	0.58 ± 0.67	0.67 ± 0.89	0.33 ± 0.49

Examination of the descriptive data in Table 13 shows that performance at rest is almost identical to that following moderate-intensity exercise. However, there was a decrement in attention following high-intensity exercise. This is illustrated in Figure 24.

Figure 24. Mean performance scores on the Stroop test following rest, moderate and high-intensity exercise

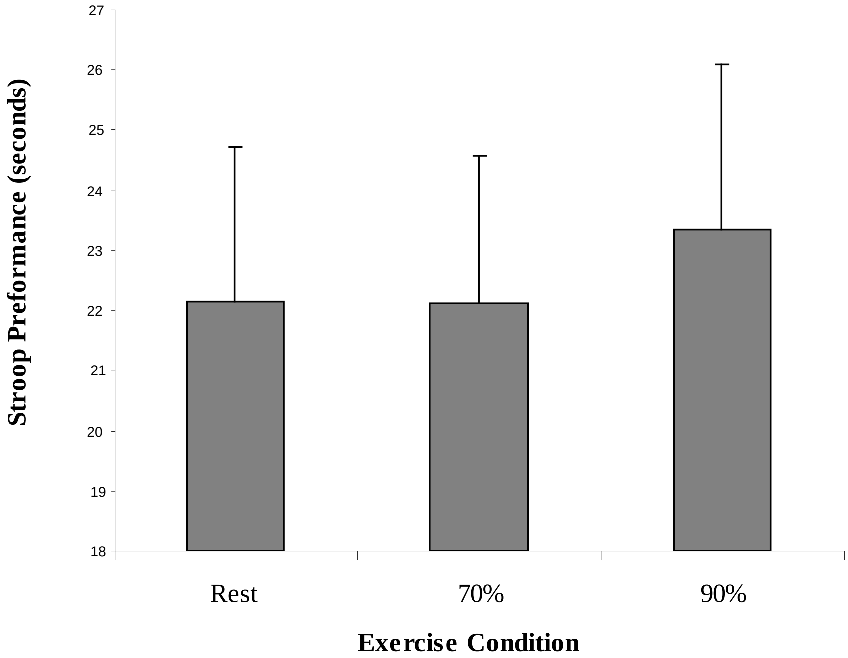


Table 14. Results of the repeated measures ANOVA conducted on the Stroop data

	Type III sum of squares	**df**	**Mean square**	**F**	**P**	**η^2**
Exercise Intensity	11.488	2	5.744	4.134	.030	.273
No. of Errors	.722	2	.361	1.202	.320	.098

The repeated measures ANOVA conducted on the number of errors revealed no main effect ($p > 0.05$). The results of the statistical analyses are presented in full in Table 14.

5.5 Discussion

It is widely assumed that arousal and anxiety have a direct influence on attention (Abernethy, 2001). In sporting situations, maintaining attention on task relevant cues is imperative to success. In the scientific literature it is very clear that the influence of acute exercise on cognitive functioning differs as a function of the exercise protocols employed (Tomporowski, 2003) and the discrepant findings in section 1.8.1 are testament to this. Because the effects of acute exercise depend on the type and duration of exercise performed, Tomporowski distinguished three types of exercise protocol. This study fits into the category of brief maximal and submaximal protocols (i.e. short duration aerobic-type exercise). It is also noteworthy that the results of the present study support the conclusions of Tomporowski with respect to such protocols.

In terms of the results here, the second research hypothesis is accepted in light of the fact that performance at rest was almost identical to that following moderate-intensity exercise, a trend which is now becoming more consistent across the studies up to now. In the present investigation, there was in essence, a negligible difference between performance at rest and that following moderate-intensity exercise. It seems therefore that moderate-intensity exercise neither improves nor leads to a deterioration in one's ability to concentrate or attend. However, as can be clearly seen in Figure 24 and from the results of the repeated measures ANOVA, there was a significant deterioration in performance following high-intensity exercise found here again and so [the CAT study aside], a trend is also emerging with respect to high-intensity exercise consistently leading to decrements in performance. The first hypothesis of a deterioration following high-intensity exercise is again accepted here.

In terms of the previous literature examining exercise effects on Stroop performance or attention, the findings of this study provide a degree of support for the findings of Miles and Roberts (1998) who also found a deterioration in Stroop Test performance following high-intensity exercise. However, Miles and Roberts (1998) also found an improvement in performance following moderate-intensity exercise which is not consistent with the findings here. Attention at rest and following moderate-intensity exercise in this study, were almost identical.

It is worth noting that the results of this study are not consistent with those of Thomson (2000) and McGregor et al. (1999). However, the protocols and tests of attention they employed differ greatly from the present work, a fact which must be considered when comparing outcomes. One study however, which shows many methodological similarities to the present work is that of Al-Nakeeb and Lyons (2007) who examined the effect of exercise at 50% and 80% HRR on the Stroop Test. In their study, performance was measured while exercising (cycling) at the desired intensities yet no difference across experimental conditions was found. The lack of difference from rest to moderate-intensity exercise is consistent in these studies therefore. However, the deterioration in performance following high-intensity exercise in this study is not consistent with the findings of Al-Nakeeb and Lyons (2007). One factor which may account for the differing results is that the criterion for high-intensity exercise in this study was 90% HRR but in the work by Al-Nakeeb and Lyons (2007) the criterion was 80% HRR. The nature of the exercise tasks was also different as the exercise in the present study was a demanding running protocol whereas in the study by Al-Nakeeb and Lyons (2007) a more progressive cycling protocol was employed and so the intensity and demand of the present protocol may underlie the differences observed here following high-intensity exercise. It is also plausible that 80% HRR is not sufficiently high to elicit a deterioration in performance. 90% HRR however, may be sufficiently high on the basis of the preliminary findings here.

In terms of the different theories of arousal and attentional processes, the results of this study are very interesting indeed. For example, these results partially support Easterbrook's (1959) cue utilisation theory and Nideffer's (1979) attention control theory. Easterbrook (1959) suggested that variations in arousal will produce a change in attentional processes. Accordingly, when arousal is low, attention is focused on both relevant and irrelevant cues and thus, performance remains poor. However, as arousal rises to a moderate level, attentional narrowing takes place. Only task-relevant cues are attended to at this point and so performance becomes optimal. If arousal continues to rise however, attention will continue to narrow and relevant cues start to be missed. Performance in this case, returns to baseline or low arousal levels. While the present study reveals no improvement following moderate-intensity exercise, a significant deterioration following high-intensity exercise is evident. The present findings again show that performance at a high-intensity drops to a level below that at rest. However, the predictions with respect to attentional narrowing are only partly consistent with the findings here. Performance at rest and performance following moderate-intensity exercise in the present study were practically the same and so there seems to be little evidence here of any form of positive attention narrowing.

The deterioration found at a high-intensity could be explained by Tomporowski and Ellis' (1986) view that physical discomfort resulting from fatiguing exercise may result in performers focusing on their perceptions of pain rather than attending to the performance task. Under high-intensity exercise conditions therefore, there is often an internalising of attention as the participant focuses on the internal signals of pain and exercise rather than upon the external stimuli (Salmela & Ndoye, 1986). The participant's subjective responses also highlighted a number of issues concerning internalising of attention and focussing on sensations of pain. Researchers such as Kahneman (1973) referred to this effect as increased distractibility. Linked to the latter point here, Kahneman's (1973) insight into arousal and cognitive effort may also find some support here. It seems that under conditions of moderate-intensity exercise, attention can be maintained at a level similar to that at rest. It is not until the intensity of exercise becomes so high or fatiguing that a deterioration in performance is exhibited. This deterioration in performance following high-intensity exercise is emerging as a common theme across the studies here. Whereas the initial studies related to sports skills, the present investigation shows that attention also deteriorates following high-intensity exercise.

5.6 Conclusion

In sporting situations where attention and alertness are required, understanding how performers respond to the numerous attentional demands under stable and variable conditions is essential for reducing the occurrence of negative performance consequences (Lal & Craig, 2002). The results of the present study show firstly, that moderate-intensity exercise had little or no influence on attention. If moderate-intensity exercise does influence attention it was certainly not evidenced in this investigation. The findings of this work therefore are at conflict somewhat with Nideffer's theory of attentional narrowing on task relevant cues. Given that attentional narrowing is an essential element of many of the theories of arousal, the results of this study have wider implications.

Secondly, the results here revealed that attention declines or deteriorates following high-intensity exercise. The fitness level or motivation of the participants was insufficient therefore, to enable them to maintain performance levels following high-intensity exercise as would be predicted by some authors (Humphreys & Revelle, 1984; Eysenck, 1992; Royal et al., 2006). Thirdly, the results show that the magnitude of decline at high-intensity exercise is greater than would be predicted by Nideffer (1979) and Yerkes and Dodson (1908). The findings of this investigation show that the deterioration in performance is to a level below resting levels.

6.0 GROUNDSTROKE ACCURACY FOLLOWING MODERATE AND HIGH-INTENSITY EXERCISE IN EXPERT AND NON-EXPERT TENNIS PLAYERS

6.1 Introduction

The present chapter describes a study examining the effect of moderate and high-intensity exercise on groundstroke accuracy in expert and non-expert tennis players. The findings up to this point in the research show some consistent trends with respect to exercise effects on performance as well as exercise effects on performance in expert and non-expert players. The results of the Stroop study demonstrated that attention at rest and attention following moderate-intensity exercise are equivalent. In fact at these intensities, performances for the most part are equivalent. The present study brings together key elements of the studies conducted up to this point but comprises the most ecologically valid design thus far, both in terms of the exercise protocol and performance task. One of the limitations of the hurling study for example, is that while the interceptive task in terms of movement and action was ecologically valid, the players were not required to intercept an actual sliotar as would be required within the game. Therefore, there is some compromise with respect to ecological validity. However, it is equally important to stress that the set-up of the Bassin anticipation timer is such that it was not possible to have the players intercept an actual sliotar.

The study described here will extend the work conducted thus far examining groundstroke accuracy in tennis at rest, moderate and high-intensity exercise conditions. Numerous papers have been published in recent years focussing on fatigue effects on performance in tennis (Booras, 2001; Davey, Thorpe & Williams, 2002; Kovacs, 2006; Marks et al., 2006; Hornery et al., 2007; Mendez-Villanueva et al., 2007). The findings of some of these papers have already been summarised in section 1.8.4 and so for the purposes of brevity will not be re-examined. A number of key themes have emerged however, from these papers and reviews. One point that many authors have identified is that success in competitive tennis may be, in part, determined by a player’s ability to resist fatigue (Mendez-Villanueva et al., 2007). Hornery et al. (2007) however, presented a number of challenges for investigators attempting to evaluate fatigue effects on tennis performance in field settings. They outlined four key limitations of past research studies which included; (1) a restricted movement approach to the multi-faceted skills that form the basis for match performance, (2) a lack of sensitivity and large variability in skill or performance measures, (3) usage of non-tennis-specific methods to induce fatigue, and (5) fatigue levels failing to reflect those recorded in match play. The present study considers the points by Hornery et al. (2007) in an effort to ensure that the procedures employed are as ecologically valid as possible. The performance task is sport-specific and an ecologically valid fatiguing task is being employed. The exercise protocol has previously been validated by Davey et al. (2003) and has a much higher degree of ecological validity than the protocols employed up to this point. The use of a more sport-specific fatiguing task will expand the scope of this work to explore whether this type of exercise (which has more transfer to the demands of the game on-court) impacts on performance in the same manner as some of the more localised exercise protocols used in this work up to now. This study will also seek to explore whether exercise effects on performance are the same in male and female players. As early as 1979, McGlynn and colleagues identified that previous studies concerning the effect of prior or concomitant exercise on performance almost always used male participants. They put forward that it is possible that women may respond to various kinds and intensities of exercise quite differently from men, but on the other hand, they may not. They concluded that there was an obvious need to examine the effect of exercise on performance in women. The majority of studies conducted since 1979 however, show a prevalence of male only participants. This study will seek to explore whether females and males respond in a similar or different way under moderate and high-intensity exercise conditions.

Finally, this study will consider one aspect of personality (achievement goal indicators). The study of personality as it relates to athletic performance has a long and rich history within the sport sciences (Gee et al., 2007). There are likely to be a host of personality factors that influence performance under exercise conditions. One such factor is motivation, or more specifically achievement motivation. As already identified in section 1.7, the importance of motivation dates back to the earlier research of Ash (1914) and Schwab (1953). Over the past 60 years, achievement motivation theorists have sought to identify and explain the factors involved in energising and directing competence-relevant behaviour (Conroy, Elliot & Hofer, 2003). A central construct in the literature on contemporary achievement motivation is that of achievement goals.

Achievement goals reflect how individuals construe (i.e. interpret and react) competence in a given achievement situation or context (Elliot, 1999).

In the domain of sport, achievement goals have been almost exclusively discussed in terms of a dichotomous mastery vs performance goal distinction (Duda & Nicholls, 1992). The 2 × 2 model (Elliot & McGregor, 2001) is the major theoretical framework that has guided research on sport participants' achievement motivation in recent years. It assumes four goals to be operational in achievement contexts: a) mastery approach (striving to attain self-/task-referenced competence), b) mastery avoidance (attempting to avoid the demonstration of self-/task-referenced incompetence), c) performance approach (focusing on the attainment of normatively referenced competence) and, d) performance avoidance (striving to avoid the demonstration of normatively referenced incompetence). Research in the physical domain has revealed mastery approach goals to be associated with positive achievement patterns, such as intrinsic motivation (e.g., Cury et al., 2002) and performance (e.g., Elliot et al., 2006). The adoption of a performance approach goal is also expected to lead to some positive consequences, but less than a mastery approach (Elliot & Conroy, 2005). Elliot and Conroy (2005) tentatively proposed that mastery avoidance goals should correspond to less positive responses. The limited studies to date in the sport domain have revealed mastery avoidance goals to be associated with maladaptive patterns (Conroy, Kaye & Coatsworth, 2006). The present study sought to explore whether this aspect of one's personality may provide some clues or insight into the factors that influence or affect a player's performance under conditions of moderate and intense exercise.

6.2 Aims and research hypotheses

This study will examine the effect of exercise at moderate and high-intensities on groundstroke accuracy in expert and non-expert tennis players. The study will again examine whether the effects of exercise intensity on groundstroke accuracy are the same regardless of expertise level. In light of the information presented in section 6.1 however, the scope of this study will be expanded in an effort to explore whether the effects of exercise intensity on performance are the same regardless of gender. Furthermore, this study will examine whether personality characteristics can provide some insight into the effects of exercise intensity on sports-related performance. Consequently, a number of research hypotheses were examined here:

1) There will be a significant decline in groundstroke accuracy in expert and non-expert players following high-intensity exercise.
2) There will be no differences in groundstroke accuracy in expert and non-expert players following moderate-intensity exercise compared to rest.
3) The performance of male and female players will show consistent trends across the three exercise intensities.
4) Player's with high approach goals will perform better across exercise intensities than those players with low approach goals.
5) Player's with high avoidance goals will perform worse across exercise intensities than those players with low avoidance goals.

6.3 Method

6.3.1 Participants

Thirteen expert tennis players (7 male and 6 female) and seventeen non-expert tennis players (13 male and 4 female) participated in this study. The players were recruited using volunteer and opportunistic sampling methods. The expert players were all current county standard players, engaged in at least three training sessions per week and playing regular competitive matches. They had an average LTA rating of 6.2, which is considered to be a very high playing standard. The non-expert players had an average LTA rating of 10.2 and comprised a number of recreational as well as club-standard players. Not all of these players had an LTA rating however, due to the fact that they were not competing in LTA rating events. Most likely, due to the demanding nature of the testing and the commitment to three testing sessions, few female novice players volunteered to take part in this study, hence the unbalanced sample. The mean age, stature and body mass of the expert tennis players was 19.5 ± 3.0 years, 175.9 ± 7.5 cm, and 71.2 ± 13.7 kg respectively. The mean age, stature and body mass of the non-expert tennis players was 24.9 ± 9.6 years, 180 ± 9.7 cm, and 73.2 ± 13.0 kg respectively.

6.3.2 Testing site

All testing was carried out on a single indoor hard-court, comprised a granular rubber base with 2 mm elastic polyurethane top layer (Pulastic 2000, Sports Surfaces International Ltd, England). The temperature was regulated and maintained between 17-19^{o} C during all tests with comfortable, stable humidity. The temperature was monitored using a digital barometer (Model BA116, Oregon Scientific, China). The court was well-lit and adequate space was available to carry out the testing required.

6.3.3 Experimental design

This study used a mixed factoral design. Each participant attended three testing sessions. Informed consent and a medical history questionnaire were completed by all participants after being fully informed of the nature and demands of the study. Parental consent was also obtained from one participant who was under the age of 16. The participant was included in this study due to the fact that he was currently competing at a very high standard, and had a very high LTA rating. A sample parental consent form is presented in Appendix IX. All procedures were reviewed and approved by the Institutional Ethics Committee. All testing conditions were counterbalanced.

6.3.4 Baseline measurements

During the initial testing session, the testing procedures were explained in full to the participants. Stature and body mass were also measured using standard methods. Participants were fitted with a heart rate monitor (Polar RS800, Polar Electro Oy, Kempele, Finland) to assess heart rate throughout the testing.

Participants were initially given five minutes familiarisation time with the tennis ball serving machine (Tennis Tutor Plus, Sports Tutor, USA) and court surface. During this time, tennis balls were fed to both the forehand and backhand sides at a frequency of 15 balls per minute. The speed of release of the ball for the warm-up was set at 66-68 km/hr. All ball service speeds were tested in advance of the study using a speed radar device. Participants were instructed to return the groundstrokes at their normal warm-up pace in any direction. Following this, participants were given five minutes to perform their typical range of stretches prior to playing tennis competitively. After a 3-5 minute rest period, participants then began their familiarisation blocks on the modified Loughborough tennis skills test.

6.3.5 The 2 x 2 Achievement Goals Questionnaire for Sport (Conroy et al., 2003)

As part of the baseline measurements, each participant also completed the Conroy, Elliot and Hofer (2003) 2 x 2 Achievement Goals Questionnaire for Sport (AGQ-S) prior to testing. The AGQ-S can be viewed in Appendix X and consists of four subscales: mastery-approach, mastery-avoidance, performance-approach and performance-avoidance. The questions in the AGQ-S provide the researcher with an indication of key goals that motivate the individual. Mastery-approach goals for example, represent striving to achieve absolute or intrapersonal competence, e.g., striving to master all aspect of personal performance. Performance-approach goals represent striving to achieve normative competence, e.g., striving to do better than others. Conversely, mastery-avoidance goals represent striving to avoid incompetence and performance-avoidance goals represent striving to avoid normative incompetence, e.g., striving to avoid doing worse than others. Each of the four subscales of the AGQ-S has been shown to have acceptable internal consistency (internal consistency estimates of 0.70, 0.82, 0.88 & 0.87 respectively) according to Conroy et al. (2003). The AGQ-S is an appropriate instrument for research on achievement goals in sport and was included in this study to explore whether an individual's approach or avoidance scores provide any insight into how they respond under varying exercise conditions. The procedures relating to how this was conducted are outlined in section 6.3.9.

6.3.6 The modified Loughborough Tennis Skills Test: Groundstrokes (Davey et al., 2002)

The modified Loughborough Tennis Skills Test (mLTST) was used to assess groundstroke accuracy. The original test was developed by Davey et al. (2002). The set-up of both groundstroke tests is illustrated in Figures 25 & 26 in Appendix XI. The test modification related to the size of the target area. In the original test, the accuracy target areas were 1.5 m^2 but for the purposes of this study this was increased to 2 m^2. This modification was made following a number of pilot studies examining the range of scores obtained from both the expert and non-expert players. The target areas of 2 m^2 were marked out in the rear singles court area using standard court markers that were placed flat on the floor. The tennis ball serving machine was positioned in the middle of the court with the front edge 0.35 m from the baseline. The experimental set-up is shown in Figure 27.

Figure 27. Experimental set-up of the groundstroke accuracy study

The familiarisation trials began with mLTST test 1, whereby the ball was served left and right alternating from the forehand (direction of feed one) to the backhand (direction of feed two) at a frequency of 20 balls per minute in a continuous manner (Figure 25). For each serve, the ball was being delivered with topspin so that it was travelling over the net at a height of 1.5 m and landing 2 m from the baseline and 0.5 m from the tramline on both sides of the court. The direction of the feeds is illustrated in Figure 25 (Appendix XI). The participants were, therefore, required to return all the shots in the order of down-the-line forehand followed by cross-court backhand, aiming every return towards target A at match pace. The test continued in this manner until twenty shots in total were completed. Twenty shots (ten down-the-line forehand shots and ten cross-court backhand shots) comprised one familiarisation block. Immediately following each block, participants were given sufficient rest (3-5 minutes) so as to allow their heart rate to return to resting levels or within 10 bpm of resting levels. When they had sufficiently recovered, they then completed another block of twenty shots. In total, three blocks of twenty shots were completed on mLTST test 1.

Following this, participants then completed three further familiarisation blocks on mLTST test 2 (Figure 26). Once again, one block comprised twenty consecutive shots whereby the ball was delivered left and right to the player in a continuous manner at a frequency of twenty balls per minute. The direction of serves was the same as with mLTST and again this is illustrated in Figure 26 (Appendix XI). The serve from the machine was kept consistent throughout all familiarisation blocks so that it was travelling over the net at a consistent height (1.5m) and landing at a consistent point on both sides of the court (2 m from the baseline and 0.5 m from the tramline). With mLTST test two, the players were required to return the balls in the order of down-the-line backhand followed by cross-court forehand aiming every return at target area B (Figure 26). Again, players were given 3-5 minutes rest time between blocks so as to allow their heart rate to return to resting levels. In total therefore, six blocks were completed and these also ensured that the player was sufficiently warmed up in preparation for the maximal tennis hitting sprint test.

Figure 28. Participant performing the mLTST

With regard to scoring the mLTST test 1, every ball that landed within the $2m^2$ area marked out as target A, or hit the perimeter lines marking out this area, was considered 'in'. Tennis balls landing within the area marked out with the diagonal white lines (Figure 25) were considered 'consistent'. Any ball that landed on the perimeter lines of this area was considered "consistent". Any returned tennis balls that hit the net were replayed. These shots were not counted in the overall scoring of the test. Any ball landing in an area other than those specified above was 'out' and did not contribute to either the accuracy or consistency scores. The scoring and replay shot guidelines here are consistent with those outlined in the original test. The raw scores for each skill test were then converted into percentages, whereby:

'Consistency' + 'Accuracy' + 'Out' Scores = 100%

Mean percentage scores were calculated for each of the above parameters. The raw percentage scores were then used in the subsequent statistical analyses. The same scoring system was used for mLTST test 2 but in this case the “in” target area was target B (Figure 26).

6.3.7 Tennis Hitting Sprint Test (Davey et al., 2003)

It has been established by a number of authors (e.g. Delamarche et al., 1987; Therminarias et al., 1991) in the existing literature that laboratory tests significantly underestimate the heart rate achieved in the field when hitting tennis balls using the arms and legs in combined exercise. For this reason, a tennis-specific sprint test developed by Davey et al. (2003) was used to obtain peak heart rate (HR_{peak}) for the purposes of setting the exercise intensity in this study. Davey et al. (2003) maintained that this test is much more specific to the movements experienced in competitive tennis matches and the peak heart rate is also much more realistic to that achieved in the field. A diagrammatic representation of the sprint test is presented in Figure 29 (Appendix XII).

The participants started the test at base A in the centre of the baseline. On the tester’s command, the participant sprinted to base one at which point a ball was dropped by the investigator for the participant to hit over the net (Figure 30). The participant then turned and sprinted back to base A. When they reached base A, the participant turned and sprinted to base two where a ball was dropped again and hit over the net. They then sprinted back to base A and the test continued in this manner with the participants sprinting to bases three, four and five, hitting a tennis ball at each and returning to base A between each hit. For each sequence, participants were required to hit a forehand groundstroke at bases one and two, a forehand approach shot at base three, a backhand groundstroke at bases four and five and then sprint back to base A (Figure 29). Each sequence was completed as quickly as possible and was followed by a ten-second recovery period. During the recovery period, heart rate and RPE were recorded by the tester in line with the procedures outlined by Davey et al. (2003). The RPE values served as an adjunct to the monitoring of heart rate. At the end of the ten-second recovery period the test sequence was repeated.

The test continued in this manner until a plateau in heart rate was observed. This was taken when two consecutive heart rates within 1-2 bpm were achieved. The higher of the two heart rates achieved during the test was recorded as HR_{peak}. From this HR_{peak} value both the moderate (70% HR_{peak}) and high-intensity (90% HR_{peak}) exercise conditions were established. The average HR_{peak} obtained during this test was 184 ± 9.2 bpm. The average number of sequences completed was 6.87 ± 1.65 and the sprint test (including 10 second rest periods) took approximately 3 minutes 43 seconds to complete. Once players had completed the baseline measures outlined here, they then performed a 3-5 minute cool-down against the ball serving machine followed by a five-minute stretching phase. The measures and procedures outlined thus far comprised the initial baseline testing session. The rest, moderate and high-intensity exercise conditions were then conducted on separate testing days.

Figure 30. Participant performing the Tennis Hitting Sprint Test

This image has been removed for data protection reasons. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University

6.3.8 Loughborough Intermittent Tennis Test (Davey et al., 2003)

On the follow-up experimental sessions, testing began with a five-minute standardised warm-up against the tennis ball serving machine, alternating feeds to the forehand and backhand sides at a frequency of 15 balls per minute. Players were informed that they could stand anywhere on court but were instructed to hit the ball as they would during normal match play. They were also instructed to practise all the different strokes required in mLTST 1 and 2. Following this, participants were given five-minutes to perform their normal range of stretches before playing tennis and then they began the Loughborough Intermittent Tennis Test (LITT).

The LITT was developed by Davey et al. (2003) and is illustrated in Figure 31 (Appendix XIII). This test consisted of bouts of maximal hitting of four minutes' duration with 40 seconds seated recovery between bouts. Participants were required to hit returns at maximum effort as they would during match play, within the singles court. The tennis ball serving machine served the tennis balls in a random fashion at a frequency of 20 balls per minute which was increased after each 4 minute period. The direction of the serves is illustrated in Figure 31 (Appendix XIII). The speed of release was consistent at 68-72 km/hr. The ball was delivered from the serving machine with top spin. As with the baseline session, it was set so that it travelled over the net at a height of 1.5m and landed within 2m of the baseline. The test continued in this manner (four minutes maximal hitting followed by 40 seconds seated recovery) with the participants returning all tennis balls at match-pace until the required exercise intensity was met as indicated by 70% HR_{peak} and an RPE of 15. Both heart rate and RPE values have been used in past work as estimates of exercise intensity in tennis (Fernandez et al., 2005; Novas, Rowbottom & Jenkins, 2003). Fernandez et al. (2005) for example, found that RPE values correlated significantly with strokes per rally and the duration of rallies. Their results therefore, indicated that RPE may be a valuable tool for tennis coaches because it provides relatively reliable and valid information about a player's physical effort during tennis matches. Novas, Rowbottom and Jenkins (2003) also reported that RPE can be used to estimate the energetic cost of playing tennis on an individual basis. RPE values have also been reported in a number of previous studies exploring match demands in tennis (Mendez-Villanueva et al., 2007; Gomes et al., 2011) as well as in studies exploring the effects of indoor intermittent tests on subsequent tennis performance (Booras, 2001; Cooke & Davey, 2005; Davey et al., 2003; Ferrauti, Pluim & Weber, 2001; Vergauwen et al., 1998).

Once both criteria were met, the LITT was continued for a further minute so as to ensure that each individual was truly at the desired exercise intensity level. Following the additional minute, the ball-serving setting was switched from random feed to wide feed and the machine then served the ball left and right to the points on the court shown in Figures 25 and 26. Players immediately completed one block of trials (20 shots) on mLTST test 1 followed by a block on mLTST test 2. This constituted the moderate-intensity exercise session. The justification for using heart rate and RPE as the two criteria has already been addressed in this thesis. The rationale behind the methods employed is that this protocol has very high ecological validity, which was a key objective throughout this work.

The high-intensity exercise testing session comprised very similar procedures to those already outlined here for the moderate-intensity exercise testing session. The player completed the LITT again, following the standardised warm-up but on this occasion the LITT continued until the player reached the 90% exercise intensity as indicated by 90% HR_{peak} and an RPE of 18. When players reached the desired intensity as indicated by both criteria, they were again required to maintain this intensity for a further minute if possible. Immediately following this additional one minute, they completed one block of trials (twenty shots) on mLTST test 1 and one block of trials on mLTST test 2. The same protocol therefore, was followed for the high-intensity exercise session but the duration of the LITT was often much longer. It took players 6.23 minutes on average to achieve the moderate-intensity exercise state on the LITT and 12.73 minutes to reach a high-intensity exercise state. The mean heart rates at both moderate and high-intensity exercise levels were 170.60 ± 7.24 bpm and 186.57 ± 7.49 bpm respectively. As well as completing the testing under moderate and high-intensity exercise states, the mLTST tests 1 and 2 were also completed on a separate occasion in a completely rested state. The order of all tests and exercise conditions was counterbalanced.

6.3.9 Statistical analysis

Across each exercise intensity (rest, moderate and high-intensity exercise) four shots were analysed during the testing sessions. These were:

- Down-the-line forehand
- Down-the-line backhand
- Cross-court forehand
- Cross-court backhand

For each shot the participant's raw scores were converted into percentages. Therefore, for each of the four shots here, 'accuracy', 'in' and 'out' percentages were calculated as a means of generating the dependent variables. Measures of central tendency (e.g. mean values) and dispersion (e.g. standard deviation) were calculated using the analysis of descriptive statistics function in SPSS. The raw data are presented in Appendix XXII. A number of 3 (exercise intensities) x 2 (levels of expertise) mixed ANOVAs were conducted on the 'accuracy', 'consistency' and 'out' percentage data. For the purposes of brevity, the percentages of both forehand shots were combined and averaged for selective analyses. Both backhand shots were also combined in selective analyses. Finally, all four shots were combined in a number of analyses in order to give an indication of overall 'accuracy', 'consistency' and 'out' percentages across the different exercise intensities.

For each analysis, the within-subject factors were the three exercise intensities (rest, moderate and high-intensity exercise). However, a number of between-subject factors were examined in separate analyses which were planned in advance of the testing and considered in the design. These include:

- Expertise level (expert and non-expert players)
- Gender (males and females)
- Approach achievement motivation (high and low approach groups)
- Avoidance achievement motivation (high and low avoidance groups)

In the case of the latter variables here, the entire group AGQ-S data were averaged. The data from the two approach subscales were combined and a mean for the entire group was calculated. High and low approach achievement motivation groups were then calculated based on whether an individual was above or below the mean for the group regardless of level of expertise. Those above the mean were categorised as a 'high approach' group and those below the mean were categorised as a 'low approach' group. The same procedure was used with the avoidance subscale data. Again, high and low avoidance achievement motivation groups were determined based on whether an individual's scores were above or below the mean for the group. Those above were categorised as a 'high avoidance' group and those below were categorised as a 'low avoidance' group again regardless of skill level. These groups were then used as a between-subject factor in subsequent analyses. Because all treatment conditions were planned, a pairwise least significant difference post hoc procedure was used in the case of significant F scores. With each analysis, the residuals of the repeated measures ANOVA were checked for normality using the Shapiro-Wilk test statistic. Homogeneity of variance was evaluated using Mauchly's test of sphericity and when violated, the Greenhouse-Geisser adjustment was used. SPSS Version 17.0 (SPSS Inc., Chicago, IL) was used for all statistical calculations. The level of significance was set at 0.05.

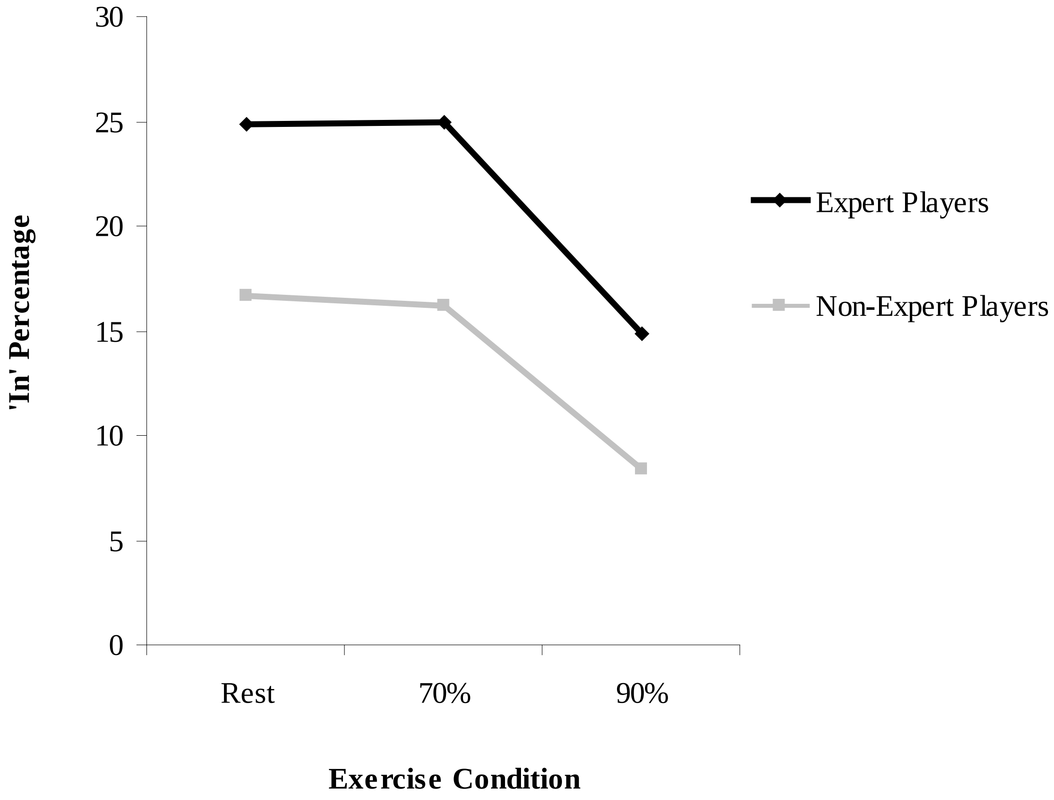
6.4 Results

The percentages for each individual shot, both forehand shots combined, backhand shots combined and all shots combined are presented in Tables 15, 16, 17 and 18 in Appendix XIV. A number of 3 x 2 mixed ANOVAs with LSD post hoc procedure were also conducted and these will be examined next.

6.4.1 Level of expertise analyses

A 3 (exercise intensities) x 2 (expertise levels) mixed ANOVA was conducted on the accuracy or 'in' percentage scores for all four shots combined and indicated that there was a highly significant main effect ($F_{2, 56} = 14.517$, $p < 0.001$, $\eta^2 = 0.341$). There was also a highly significant between-group difference ($F_{1, 28} = 10.302$, $p = 0.003$, $\eta^2 = 0.269$) illustrated in Figure 32. No exercise intensity by level of expertise interaction was found ($p > 0.05$). LSD post hoc procedure revealed a highly significant ($p < 0.001$) difference between performance at rest and that following high-intensity exercise. Similarly, there was a highly significant ($p < 0.001$) difference between performance following moderate-intensity exercise and performance following high-intensity exercise. The nature of these differences is clear in Figure 32.

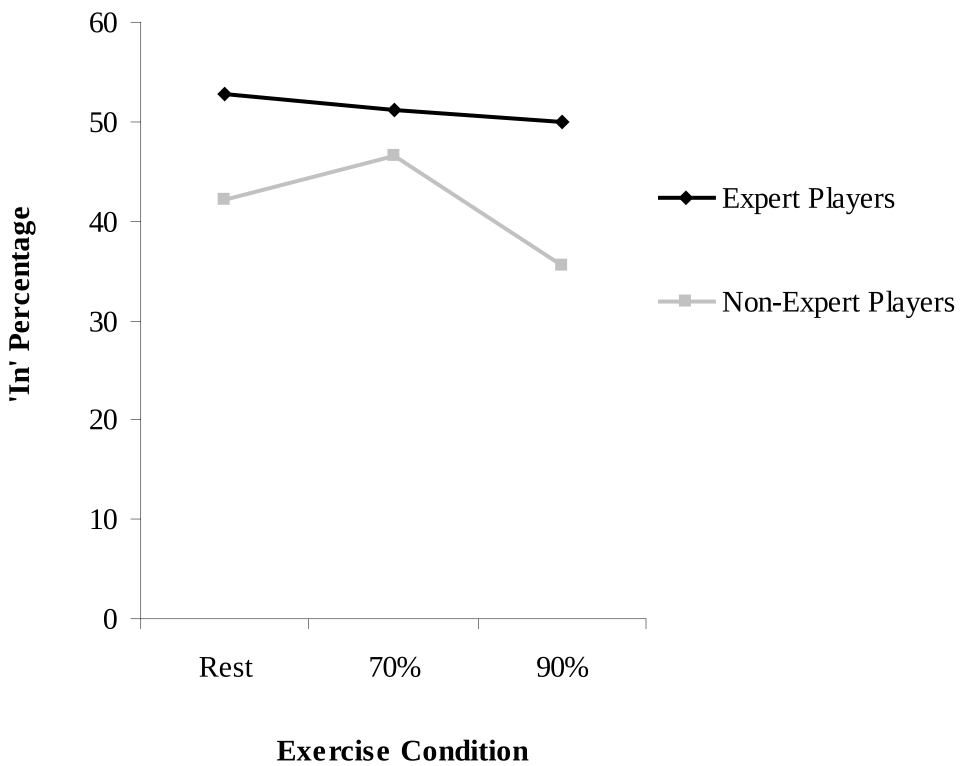
Figure 32. Percentage of 'in' shots across exercise intensities in expert and non-expert tennis players (all groundstrokes combined)



When both forehand shots were combined again similar results were evident. These are illustrated in Figures 33 and 34 (Appendix XV). When the backhand shots combined are compared to the forehand shots combined, however, slightly different trends emerge in terms of percentage accuracy across exercise intensities.

A 3 (exercise intensities) x 2 (expertise levels) mixed ANOVA was conducted on the 'out' percentage scores for all four shots combined and again revealed a highly significant exercise intensity effect ($F_{2, 56} = 27.301$, $p < 0.001$, $\eta^2 = 0.494$) and a highly significant between-group effect ($F_{1, 28} = 33.407$, $p < 0.001$, $\eta^2 = 0.544$). The results here once again illustrate that there are marked differences in the number of 'out' shots performed by expert and non-expert players across the three exercise intensities. LSD post hoc procedure revealed similar trends to those found for the 'in' or accuracy percentages. A highly significant difference was found between performance at rest and that following high-intensity exercise. Furthermore, there was a highly significant difference between performance following moderate and high-intensity exercise (both, $p < 0.001$). The nature of these differences is illustrated in Figure 35. Again, no exercise intensity by level of expertise interaction was found ($p > 0.05$).

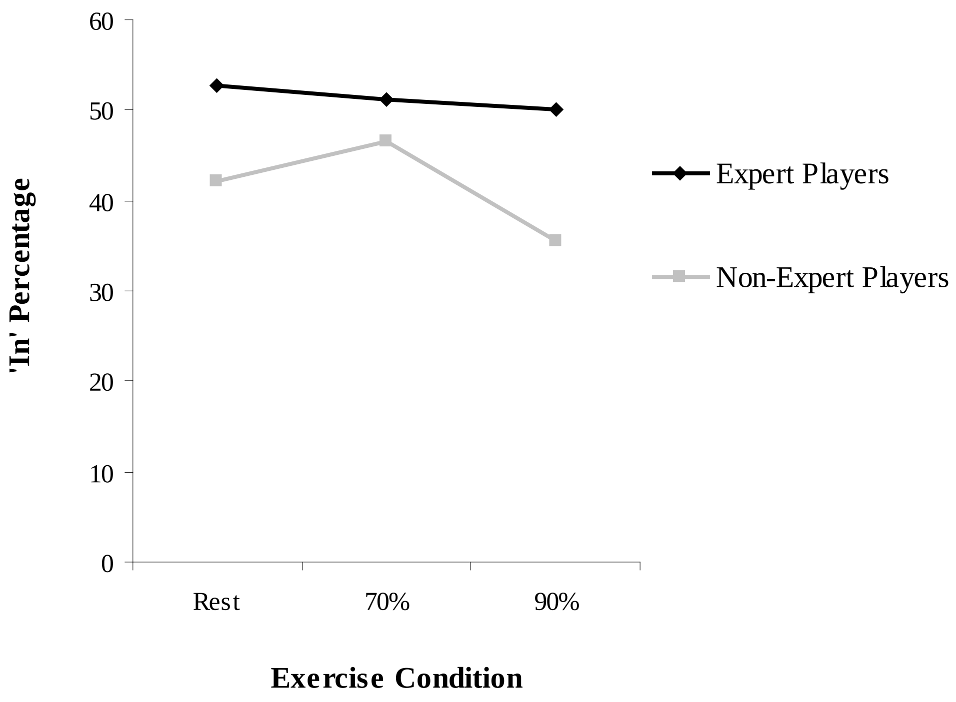
Figure 35. Percentage of 'out' shots across exercise intensities in expert and non-expert tennis players (all groundstrokes combined)



When both forehand shots were combined similar trends emerge. This is also the case when both backhand shots were combined. The nature of the trends are illustrated in Figures 36 and 37 (Appendix XVI).

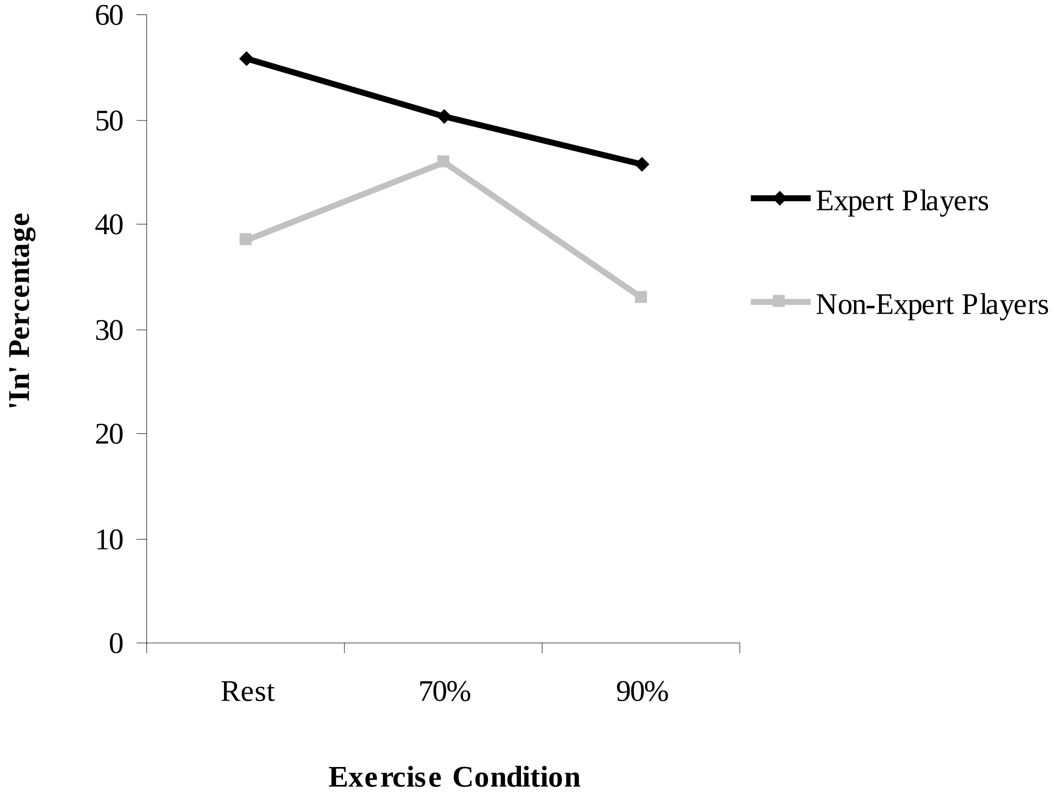
The final analyses examined the consistency data. A 3 (exercise intensities) x 2 (expertise levels) mixed ANOVA was again conducted. A highly significant overall effect of exercise intensity was found ($F_{2, 56}$ = 5.093, p = .009, η^2 = 0.154). There was also a highly significant between-group difference ($F_{1, 28}$ = 15.391, p = .001, η^2 = 0.355) but no exercise intensity by level of expertise interaction ($F_{2, 56}$ = 3.145, p = .051, η^2 = 0.101), although the p value is suggestive that there may be a trend here. LSD post hoc procedures revealed differences between performance at rest and high-intensity (p = .026) as well as a highly significant difference between performance following moderate and high intensities (p = .002). With respect to the consistency of expert and non-expert players, therefore, there are trends that are dissimilar to those shown thus far. The nature of the contrasts are illustrated in Figure 38.

Figure 38. Percentage of 'consistent' shots across exercise intensities in expert and non-expert tennis players (all groundstrokes combined)



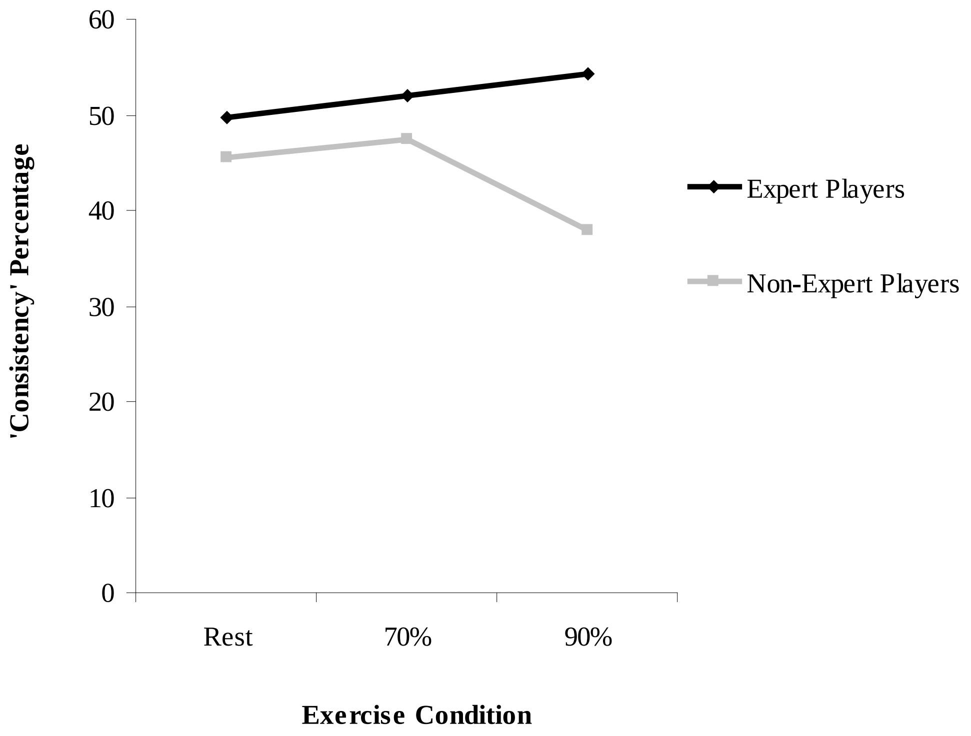
When both backhand shots were combined again similar trends emerge as illustrated in Figure 39.

Figure 39. Percentage of 'consistent' shots across exercise intensities in expert and non-expert tennis players (backhand groundstrokes combined)



When forehand shots alone were combined (Figure 40) consistency under high-intensity exercise declines in the non-expert players while consistency in the expert players improves. The results of the analyses in this section are reported in full in Table 19 (Appendix XVII).

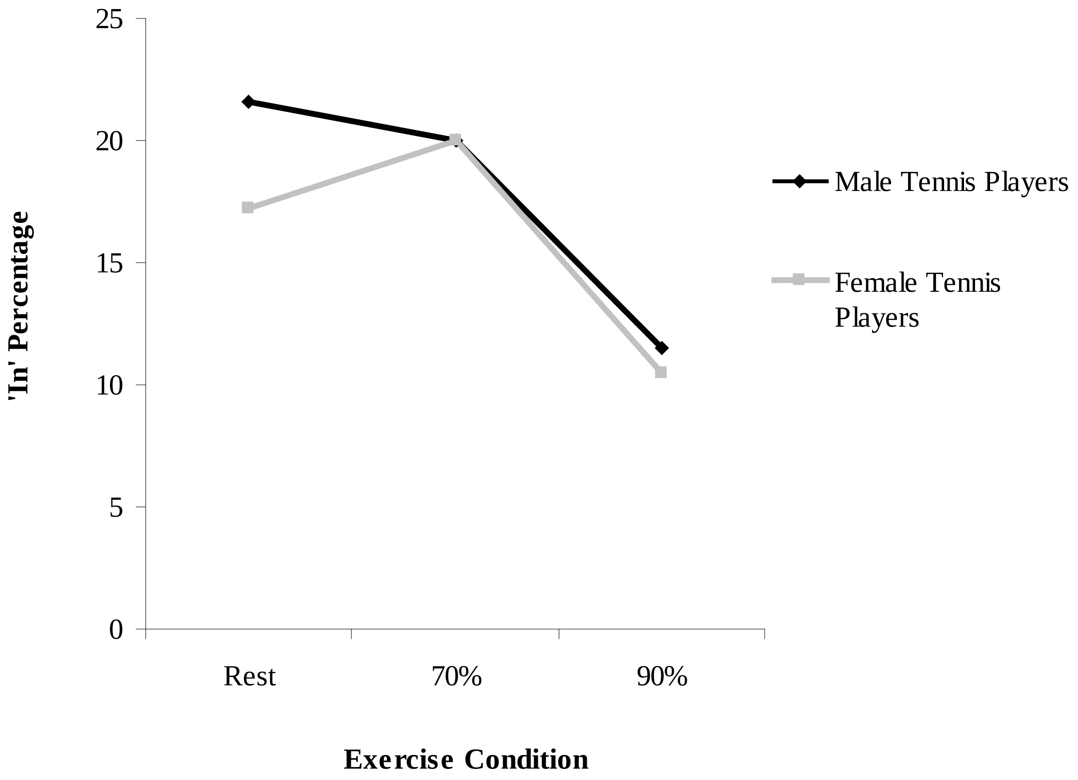
Figure 40. Percentage of 'consistent' shots across exercise intensities in expert and non-expert tennis players (forehand groundstrokes combined)



6.4.2 Gender analyses

A 3 (exercise intensities) x 2 (males and females) mixed ANOVA was conducted on the accuracy percentage scores for all four shots combined and indicated that there was a highly significant exercise intensity effect ($F_{2,\ 56} = 12.404$, $p < 0.001$, $\eta^2 = 0.307$). LSD post hoc procedures revealed that there was a highly significant difference between performance at rest and high-intensity. There was again a highly significant difference between groundstroke accuracy at moderate compared to high-intensity exercise (both, $p < 0.001$). No exercise intensity by gender interaction was found however, and no between-group differences (both, $p > 0.05$). The performance of both groups at rest was analysed further by means of an independent t-test in an effort to explore whether the differences evident at rest (Figure 41) were significantly different. The t-test revealed that this was not the case ($p > 0.05$).

Figure 41. Percentage of ‘in’ shots across exercise intensities in male and female tennis players (all groundstrokes combined)



Consistency percentages (all four shots combined) were explored using the same range of analyses and again a significant exercise intensity effect was found ($F_{2,\ 56}$ = 4.051, p = 0.023, η^2 = 0.126) as well as a significant exercise intensity by gender interaction ($F_{2,\ 56}$ = 3.457, p = 0.038, η^2 = 0.110). No between-group differences were found (p > 0.05), however. The interaction is presented in Figure 42 (Appendix XX). LSD post hoc analyses revealed there was a significant (p = .024) difference between consistency scores at rest compared to high-intensity exercise. There was also a significant (p = .012) difference between consistency scores following moderate and high-intensity exercise.

Finally, a 3 (exercise intensities) x 2 (males and females) mixed ANOVA was conducted on the ‘out’ percentage data and again a highly significant exercise effect was found ($F_{2,\ 56}$ = 22.636, p < 0.001, η^2 = 0.447). No exercise intensity by gender interaction or between-group differences were found however, with respect to groundstroke ‘out’ percentages (both $p > 0.05$). This is illustrated in Figure 43. The results of the analyses are reported in full in Table 20 (Appendix XVII).

6.4.3 Achievement motivation – approach analyses

Concerning the AGQ-S scores, the expert and non-expert players were grouped into ‘high approach’ and ‘low approach’ groups based only on their AGQ-S responses. The high and low approach groups therefore were then used as a between-subject factor in subsequent analyses. A 3 (exercise intensities) x 2 (high and low approach) mixed ANOVA was conducted on the accuracy scores and a highly significant exercise intensity effect was found ($F_{2, 56} = 14.513$, $p < .001$, $\eta^2 = 0.341$). There was no exercise intensity by group interaction however and no significant between-group effect (both $p > 0.05$). LSD post hoc analyses revealed a highly significant difference between performance at rest and 90% ($p < .001$) and a highly significant difference between the accuracy scores following moderate and high-intensity exercise ($p < .001$).

The same range of analyses were conducted on the ‘consistency’ percentage data. Once more, a highly significant exercise intensity main effect was found ($F_{2, 56} = 5.889$, $p = .005$, $\eta^2 = 0.174$). Again no between-group differences or exercise intensity by group interaction was found (both $p > 0.05$). LSD post hoc analyses revealed a highly significant difference between the consistency of shots played at rest compared to that following high-intensity exercise ($p = .002$) and a significant difference between the consistency following moderate and high exercise intensities ($p = .015$).

With respect to the ‘out’ percentages the same analyses were conducted with the same trends emerging. Again there was a significant overall main effect for exercise intensity ($p < .001$), no between-group effects ($p > 0.05$) or exercise intensity by group interaction ($p > 0.05$). LSD post hoc analyses revealed a highly significant difference between the percentage of out shots at rest compared to that following high-intensity exercise ($p < .001$) and a highly significant difference between the percentage of out shots following moderate and high intensities ($p < .001$). The results of all the analyses here are presented in full in Table 21 (Appendix XX).

This series of analyses here in the main, suggest that exercise effects on performance are equivalent regardless of whether a player scored high on the approach elements of the AGQ-S or not.

6.4.4 Achievement motivation – avoidance analyses

The expert and non-expert players again were grouped into 'high avoidance and 'low avoidance' groups based only on their AGQ-S responses. The high and low avoidance groups were then used as a between-subject factor in the mixed ANOVAs. The same range of analyses as described in the previous section were conducted. Therefore, 3 (exercise intensities) x 2 (high and low avoidance) mixed ANOVAs were performed on the 'accuracy', 'consistency' and 'out' data again. Again highly significant exercise effects were found with all analyses (all, $p < .01$). No exercise intensity by avoidance interaction or between-group differences were found with all the analyses (all $p > .05$). The LSD post hoc analyses again revealed the same trends as those outlined for the 'approach' analyses and so will not be repeated here again in the interests of brevity. The results of these analyses are presented in full in Table 22 (Appendix XXI).

6.5 Discussion

This study sought to bring together a number of key objectives of this research programme. The present study aimed at developing exercise states using a tennis-specific protocol which mimics much more closely the type of movements, responses and level of exercise exhibited in competitive match play. The performance task was also sport-specific and ecologically valid. This study explored many themes common to those studies conducted thus far, namely whether exercise effects on performance are the same regardless of level of expertise. However, this section of the study expanded the scope of work by including gender as a between-subjects factor. Therefore, an additional aim of this study was to examine whether exercise effects on performance in tennis were the same in male and female players. Finally, this study aimed at exploring one aspect of motivation, that being an individual's achievement motivation. The final analyses therefore, explored whether there is an interaction between an individual's scores (approach and avoidance) on the AGQ-S and their performances under exercise conditions.

Regarding the effects of exercise intensity on performance, almost all the analyses conducted revealed highly significant main effects. Many of the procedures used in this study were derived from the work of Davey et al. (2002 & 2003) and so it seems pertinent to explore the results found here in relation to their findings. Davey et al. (2002) also examined the effect of the LITT on tennis performance but they continued the LITT until volitional exhaustion in a distinct group of elite players. They found a significant decline in groundstroke accuracy. However, this decline was not evident in all the groundstroke shots as some were unaffected by exercise intensity. In the present study, the results and trends are similar to those exhibited by the expert players in the basketball study. Many of the graphs presented in this chapter illustrate that performances at rest and following moderate-intensity exercise were equivalent. However, a consistent decline in groundstroke accuracy following high-intensity exercise level was exhibitd here. The first two hypotheses therefore in section 6.2 are accepted in light of the initial findings here.

The level of expertise analyses again revealed that expert players were capable of maintaining a higher level of performance compared to the non-expert players across all exercise intensities. For example, the expert players maintained a higher percentage of 'in' shots across the three exercise intensities (Figures 32-34). Expert players also hit fewer 'out' shots across the three intensities (Figures 35-37) and were more consistent. The results here were true regardless of whether the forehand shots were combined, backhand shots were combined or all shots were combined. In each of the 3 x 2 ANOVAs where level of expertise was the between-group factor a highly significant between-group effect was found although it is important to also acknowledge that no exercise intensity by level of expertise interactions were found. The superior performance of the expert players across the three exercise intensities therefore is not consistent with the findings of the basketball and hurling studies in the sense that no between-group differences were found in these studies. This pont aside, there is a trend towards the performance of the expert players being better (albeit not significantly better statistically) across moderate and high-intensity exercise conditions. Expert players in the present study, seemed more capable of maintaining a higher level of performance than the non-expert players across exercise conditions. A number of the graphs presented as part of this chapter show that in general, the changes over the three intensities are parallel between the expert and novice players (e.g. Figures 34 & 36). Figure 33 for example, illustrates how percentage of accuracy or 'in' shots change across the three exercise intensities. It is clear from this graph that the rate of decline in accuracy from rest to moderate exercise conditions is small and is the same regardless of expertise. Following moderate intensity exercise however, the rate of decline of the expert players thereafter seems, if anything more accelerated compared to the non-expert players. Statistically, the between-group analyses in the present study were all highly significant with practical effects ranging from 0.269 to 0.544. The performance of both the expert and non-expert players in this study, in the main, support Janelle and Hillman's (2003) assertion that expert performers may be capable of dealing with affective states more appropriately. This is emphasised in the fact that they maintain a higher level of performance across all exercise conditions.

With respect to the range of analyses examining within and between-group differences in male and female tennis players, a number of interesting preliminary findings were revealed here. Firstly, with all the analyses conducted ('in', 'out' and 'consistency') significant exercise intensity effects were found for each analysis. There were no between-group effects observed however, across the 'in', 'out' and 'consistency' data suggesting that both groups perform at comparable levels across the different exercise conditions and so the third research hypothesis is also accepted in light of the results here. When figures 42 and 43 are viewed, it is also noticeable that 'out' and 'consistency' percentages following moderate-intensity exercise were identical in the male and female players. Consequently, it seems both males and females perform at comparable levels under moderate-intensity exercise conditions especially but there is similarity also at rest and high-intensity exercise conditions. It is important to note that this was the only study where gender analyses could be conducted as in all of the previous investigations, only male participants were used. This was due to the difficulty in recruiting volunteers for experimental work of this nature. Aside from the strenuous nature of some of the testing, participants are also required to attend three separate testing sessions. Much more research encompassing male and female groups is clearly warranted (McGlynn, Laughlin & Rowe, 1979) so as to add to the preliminary findings here.

Finally, it has long been established in the literature relating to this topic that future researchers need to examine experimentally how different levels of motivation in conjunction with varying exercise intensities and durations may affect cognitive performance (Szabo & Gauvin, 1992). This is also important in terms of exercise effects on sports performance. A number of past studies have acknowledged the importance of motivation but to date, there has been little attempt to incorporate a measure of motivation into studies of this nature. Arnett, DeLuccia and Gilmartin (2000) conducted research into various aspects of muscle fatigue but point out that their findings need to be interpreted with one key point in mind, namely, the fact that they have not manipulated motivation in any way. There is recognition among researchers, therefore, that motivation is important. This is emphasised in section 1.7. However, incorporating an objective measure of motivation into studies of this nature does present a challenge.

The present study sought to explore one aspect of motivation, namely achievement goals and whether one's approach or avoidance motivation interacted with performance under moderate and high-intensity exercise states. The AGQ-S data were analysed based on the avoidance and approach subscales, with high and low groups developed for each based on a split mean. It was hypothesised that those players who scored high on the approach scale may perform better than their low approach counterparts due to their positive achievement patterns and intrinsic motivation. Furthermore, it was hypothesised that those who scored high on the avoidance may suffer greater decrements in performance with increasing intensities as avoidance goals have been associated with maladaptive patterns (Conroy, Kaye & Coatsworth, 2006). The same range of analyses were conducted on the groups categorised according to whether they scored above or below average for the approach elements of the 2 x 2 AGQ-S. The most notable finding however, was that there was no exercise intensity by approach interaction or between-group differences (all, $p > 0.05$). The groups therefore, seem to perform comparably across exercise intensities regardless of their achievement goal orientation. With respect to the avoidance subscale and subsequent analysis the same trends were found (no between-group differences or exercise intensity by group interaction). It seems therefore, that a player's achievement goal indicators assessed using the AGQ-S impacted little on their performance scores across exercise conditions and so the research hypotheses predicting significant performance differences here are all rejected.

6.6 Conclusions

In tennis, coaches, athletic trainers and players often attribute the final outcome of a match to decreases in hitting accuracy subsequent to mental mistakes and/or decreases in physical performance as players tire (Mendez-Villanueva et al., 2007). It is clear from the range of analyses conducted here, that the performance of the expert players and novice players in many instances across exercise intensities contradict the classic theories of arousal proposed by Yerkes & Dodson (1908) and Hull (1943). It could be argued that the results are more consistent with those predictions of Kahneman (1973) in light of the fact that performance at rest and performance following moderate-intensity exercise in many instances are comparable (possibly due to appropriate or effective allocation of resources) but following exercise at a high-intensity due to the competition for these cognitive resources, performance deteriorates to a level below that at rest. In the latter instance, insufficient resources can be allocated to the task to maintain optimal performance.

The results also provide evidence contrary to the claim by Eysenck (1992) that highly motivated performers can perform tasks optimally even when highly aroused. In each analysis, performance following high-intensity exercise deteriorated to a level below that at rest. Underpinning the lack of agreement here could be the fact that arousal is not a unitary concept, rather it is complex and multidimensional. It includes a physiological dimension paired/grouped with a cognitive, affective, and/or behavioural dimension (Zaichkowsky & Baltzell, 2001). The nature of the tasks being performed here therefore, while extremely challenging and stressful may not be so stressful as to induce high arousal. In summary, the physiological responses that emanate as a result of the intermittent exercise task in this study may differ to those responses associated with a 'high arousal' state, hence the lack of agreement. A number of past authors (Brisswalter, Collardeau & René, 2002; McMorris & Keen, 1994; McMorris et al., 1999) have stated that the relationship between exercise and arousal is still unclear and may not be synonymous and so additional exploration of this relationship is needed.

7.0 DISCUSSION

7.1 Introduction

Fatigue is one of the most common sensations of everyday life and in a healthy person can range from a somewhat pleasant feeling to one of pain and complete exhaustion. During explosive, short duration sports such as the discus or shot put, the fatigue is relatively unimportant as the activity is often over before fatigue sets in. However, in team sports, which are the main focus of this work, fatigue is critically important. As players become tired, skills begin to deteriorate, mistakes are made and goals or points are often conceded (Jones, 1999). It is clear therefore, that exercise to the point of fatigue can have a major effect on the performance of players in sport and consequently, have a major effect on sporting outcomes. The nature and causes of fatigue as well as effects on performance have been the subject of much debate, scrutiny and research over the years. However, the vast majority of this research has been laboratory-based and despite the plethora of scientific literature relating to these topics, many questions remain.

It is inconceivable that, in the present day, the mere term ‘fatigue’ is still problematic and no universally-accepted definition exists among researchers. What is clear is that it is a highly complex physiological state, involving a wide array of both central and peripheral aspects. Furthermore, it seems highly probable that there are also a host of psychological aspects associated with fatigue states, the roles of which are largely unknown. The subject, therefore, has posed a significant challenge to researchers, even causing earlier researchers (Muscio, 1921) to suggest abandoning the concept altogether. In this thesis, the term ‘fatigue’ was used in cases where this term is stated by the respective authors. However, the term ‘exercise-intensity’ was adopted in this research, in light of suggestions by Winter (2006) that the expression ‘‘exercise intensity” be used to describe exercise challenges, irrespective of the form of exercise. This term more accurately reflects the nature of the field-based exercise protocols that form the basis of the studies conducted within this research program. Regardless of the operational definition, this topic remains as intriguing as ever and continues to raise new questions and lines of enquiry.

7.2 The effects of exercise intensity on the performance of sports skills

The ability to exercise repeatedly at a high-intensity with short recovery periods is recognised as being very important for maintaining cognitive, movement and skill performance during matches (Psotta et al., 2005). The soccer, basketball and tennis studies here examined the effects of exercise at moderate and high intensities on passing performance and groundstroke accuracy.

With particular reference to soccer, it has been highlighted that the behaviour and match phenomena attest to the occurrence of fatigue (Reilly, 1997). It has also been established that the anaerobic system is highly taxed during intense periods of the game (Bangsbo, 1994; Reilly, 1997; Mohr, Krustrup & Bangsbo, 2003; 2005; Apriantono et al., 2006; Bangsbo, Mohr & Krustrup, 2006; Bangsbo, Iaia & Krustrup, 2007). Even elite players have been shown to experience temporary fatigue during and towards the end of matches (Bangsbo, Iaia & Krustrup, 2007; Reilly, Drust & Clarke, 2008). Additionally, the most decisive actions in soccer are covered by means of anaerobic metabolism and these actions are crucial in terms of match outcome (Stølen et al., 2005). In basketball, the physiological requirements of the game are also high as evidenced by high lactate values and sustained high heart rate values (McInnes et al., 1995). The elevated lactate levels indicate that glycolysis makes an important contribution to energy requirements. In basketball, the anaerobic component is more activated than the aerobic component (Crisafulli et al., 2002) so much so that Hoffman and Maresh (2000) labelled basketball as an ‘anaerobic’ sport.

The importance of fatigue in tennis has been noted by a number of prominent researchers (Booras, 2001; Davey, Thorpe & Williams, 2002; Kovacs, 2006; Marks et al., 2006; Hornery et al., 2007; Mendez-Villanueva et al., 2007). The soccer, basketball and tennis investigations therefore, considered the findings of the studies cited here. Anaerobic-type exercise tasks were chosen for the basketball and soccer investigations but a much more sport-specific intermittent protocol was employed with the tennis study. This was facilitated by the fact that one such protocol was published in detail in the scientific literature. More importantly, however, was the fact that the fatiguing task impacted on the muscle groups used in the respective performance tests. Arnett, DeLuccia and Gilmartin (2000) used an anaerobic fatiguing task in their study with the justification that anaerobic fatiguing tasks are more reflective of the fatigue experienced during games. This was considered in the initial investigations conducted here.

The initial two investigations examined the effects of moderate and high-intensity exercise on passing performance. The soccer study examined the effects of moderate and high-intensity exercise on soccer passing performance. The test used required weighted instep passing of the ball, close ball control within a confined space, spatial awareness of the cones within the shooting grid and dribbling a ball within a very confined space. The results of this study showed a significant (p = 0.010) difference between the overall performance scores at rest, moderate and high-intensity exercise. Post hoc procedures revealed that there was a significant (p = 0.03) difference between performance at rest and performance following high-intensity exercise. Additionally, a highly significant difference (p = 0.003) was found between scores following moderate and high-intensity exercise conditions. The descriptive data identified that performance at rest was satisfactory, performance was then improved following moderate-intensity exercise but following high-intensity exercise performance deteriorated significantly compared to the other two conditions.

In order to further evaluate the performance of the players during this test, the number of penalties incurred due to poor passing alone were analysed in a separate repeated measures ANOVA. Overall time penalties (passing errors, control errors and time errors totalled) were also analysed. With both analyses, there were highly significant differences between performances at rest and those following high-intensity exercise. There was also a significant difference between performance following moderate-intensity exercise compared to high-intensity exercise. Performance at rest and that following moderate-intensity exercise were equivalent however. Both analyses revealed that passing and overall time penalties increased significantly following exercise at a high-intensity. These errors underlie the observed decrement in performance following high-intensity exercise in this study. Compared to resting performance, soccer passing improved by 3% following moderate-intensity exercise but deteriorated by 7.9% following high-intensity exercise.

When comparing the results of the soccer study to prior research on this same topic, it is necessary to consider that in most cases, the type and duration of exercise differ greatly from study to study as do the performance tasks. Likewise, any comparisons drawn need to be interpreted with these methodological differences in mind. One study using similar methods by McMorris et al. (1994) examined the effect of moderate (70% MPO) and fatiguing exercise (100% MPO) on soccer passing performance. They found that for total points scored and absolute constant error, performance following exercise at 70% MPO was significantly ($p < 0.01$) better than in the other two conditions. The results of the soccer study however, showed that performance following moderate-intensity exercise was equivalent to that at rest. Therefore, the findings of the soccer study are dissimilar to the findings of McMorris et al. (1994) where moderate-intensity exercise is concerned.

The deterioration in performance following high-intensity exercise found in the soccer study is also inconsistent with the findings of McMorris et al. (1994). In the soccer study a significant ($p = 0.030$) deterioration in soccer passing performance was evident following high-intensity exercise, compared to resting performance. However, McMorris et al. (1994) found no such difference in their study. Consequently, while the findings of McMorris et al. (1994) were discussed in terms of inverted-U effects predicted by Yerkes and Dodson (1908), no such trends are evident here. In fact, the results of the soccer study were more indicative of an inverted-J effect.

The discrepancy in findings could be due to the fact that in the McMorris et al. (1994) study the passing test took 90 seconds to complete whereas the soccer passing test conducted in this research took approximately 30 seconds to complete. It has been noted earlier in this work that biochemicals like acetylocholine, potassium, adenosine triphosphate and phosphocreatine are quickly replenished following the cessation of exercise. This is particularly the case with fit athletes (Åstrand et al., 2003). Speed of recovery, therefore, can be problematic if measurements are not made immediately on exercise cessation (Cairns et al., 2005) but recovery may also be problematic if the duration of the performance task is too long. It is possible that in the study by McMorris et al. (1994) the duration of the passing test (90 seconds) may have allowed for some recovery to have taken place. Conversely, in the soccer study conducted as part of this work, performance started immediately once the desired intensity was reached and the test was completed often within 30 seconds. Recovery from the ensuing exercise was therefore, highly improbable. The latter points may partially explain the lack of agreement between the findings of the initial study on soccer and that conducted by McMorris et al. (1994) following high-intensity exercise.

The findings of the soccer study also show some similarity to those of Ali and Gant (2007) who examined the effect of a 90-minute intermittent shuttle running test on the same passing test. Their results showed that performance deteriorated by 5.41% towards the end of the intermittent shuttle running test although this was not statistically significant. In the soccer study, the percentage difference was found to be 7.9% and statistically significant. Both studies show similar trends however. McGregor et al. (1999) also examined the influence of intermittent high-intensity shuttle running on the performance of a soccer skill and found a 5% decline in performance which was statistically significant ($p < 0.05$). Therefore, the findings of the initial study on soccer show similarity to those of McGregor et al. (1999). The findings from the soccer study also support selected research findings with overtly different methodologies (Davey et al., 2002; Evans et al., 2003; Williams & Singer, 1975; Went & El-Sayed, 1994). This study reinforces further the findings of Al-Nakeeb et al. (2003) who also found a deterioration in gross-motor performance following localised muscle fatigue at a high-intensity. Unsurprisingly, the findings are also inconsistent with some previously published studies on other sports (Squadrone, Rodano & Galozzi, 1995; Royal et al., 2006) where no differences in shooting performance were found with fatigue.

On closer examination of the group data for the soccer study, it was noted that within the data set, there were many individual differences in terms of how players performed across exercise intensities. Worthy of note however, was the fact that two of the participants within the sample exhibited little deterioration in scores following high-intensity exercise, while their performance was actually better following moderate-intensity exercise. On closer examination of their profiles, it was revealed that the two participants highlighted were the only semi-professional level players in the sample. It has previously been hypothesised by Janelle and Hillman (2003) that, because experts are more capable of demonstrating superior performances than non-experts, they may also be capable of dealing with affective states more appropriately. The results of the semi-professional players in the soccer study provided an indication that this may be true. Previous research by McMorris and Graydon (1996b) has suggested that expert players and fit individuals are better able to cope with changing conditions such as physiological stress and can overcome the negative effects of high physiological arousal. Given the findings of the soccer study, it then seemed pertinent to expand the scope of this work to explore whether moderate and high-intensity exercise effects were the same regardless of level of expertise. The basketball study therefore, had many similar characteristics to the soccer study in terms of design and exercise protocol but examined whether exercise effects on performance were the same in expert and non-expert players.

The results of the basketball study again revealed a highly significant ($p < 0.001$) exercise intensity effect and crucially, a highly significant ($p = 0.01$) exercise intensity by level of expertise interaction (Figure 15). Despite the lack of between-group differences, the interaction demonstrated that the rate of decline across the exercise intensities was different in expert and non-expert players. This was explored by means of the three independent t-tests. The first t-test confirmed that there was a highly significant difference in the rate of decline (Δ) of expert and non-expert players from rest to moderate-intensity exercise ($p = 0.01$). There was also a highly significant difference in their rate of decline from the rest condition to the high-intensity exercise condition ($p = .005$). No significant differences in the rate of decline from the moderate to high-intensity exercise conditions ($p > 0.05$) was exhibited. Therefore, while there were no between-group differences or differences according to the level of expertise, the basketball study revealed that the performance of the novices declined at a greater rate. This is illustrated in Figure 15. In percentage terms, the rate of decline from rest to high-intensity exercise in the non-expert players was 21.54% but in the expert players was just 10.8%. The findings provide further support for the contention by Janelle and Hillman (2003) that experts may be capable of dealing with affective states more appropriately than non-experts. Figure 15 illustrates that the expert players performed better than the non-expert players across both moderate and high-intensity exercise conditions despite the absence of a between-group effect. The reasons underpinning why the novices declined at a greater rate could be numerous. McMorris and Graydon (1996b) claimed that expert players are better able to cope with physiological stress. Fundamentally, however, in this study expert players were not able to completely overcome the negative effects of physiological stress. The basketball investigation provided evidence however, that there are marked differences in the way in which expert and non-expert players perform with increasing levels of exercise. It was evident that exercise may need to be of a very high-intensity for a deterioration in the performance of expert players to be exhibited.

Comparison of the results of the basketball study with those sport-specific studies already outlined in section 1.8.4 is complex due to the lack of similar work. What is clear is that the deterioration in performance following high-intensity exercise in both groups supports many laboratory-based studies examining exercise effects on gross motor performance (Cotton et al., 1974; Spano & Burke, 1976; Evans & Reilly, 1980; Berger & Smith-Hale, 1991; Went & El-Sayed, 1994; Al-Nakeeb et al., 2002 & 2003). The results of the basketball study also lend support to many of the studies conducted on other sports such as the research by Chmura, Nazar and Kaciuba-Uścilko (1994) who found that immediately following exercise (which induced increasing blood lactate), it was impossible for soccer players to resume effective play. They also suggested that only after approximately two minutes does such a player become capable of resuming effective play. The performance task in the basketball and soccer studies, was completed immediately following high-intensity exercise and lasted just 30 seconds in each case. This would have kept lactate levels at a high level in the active muscle. Our findings therefore, mirror the findings of Chmura, Nazar and Kaciuba-Uścilko (1994) and lend support to the argument that, immediately following fatiguing exercise (which induces increasing blood lactate) it is very difficult for players to resume effective play.

In summary, the soccer and basketball studies showed that performance following exercise at a high-intensity leads to a deterioration in performance, regardless of level of expertise. The basketball study also showed that the rate of decline in the performance of the expert players is much less than that of their non-expert counterparts. With respect to soccer study there were also some trends with respect to a small number (N = 2) of semi-professional players, namely that their performance declined very little following high-intensity exercise when compared to the decrements observed with the rest of the sample (collegiate-level players). The initial two investigations provide a degree of support for the suggestion that expert players are capable of dealing with exercise states and the associated physiological stress much better than non-expert players. They are more consistent across the exercise conditions. There are also simililarities however, in terms of the fact that both expert and non-expert players exhibited a deterioration in skilled performance following high-intensity exercise.

Moreover, the results of the tennis study revealed trends very similar to those in the basketball study, despite the fact that the protocols and procedures were very different. In the case of the tennis study, a sport-specific intermittent protocol was used. The protocol comprised four-minute stages with 40 seconds seated recovery in between stages. However, very similar effects on performance were exhibited when compared to the basketball study. One of the main analyses in the tennis study was conducted on accuracy scores and despite the vastly different methodologies, similar results were found in terms of exercise effects on performance. The results of the tennis study (as with the soccer and basketball investigations) revealed highly significant exercise intensity effects but also highly significant between-group differences across all the analyses conducted. Therefore, whether the analysis explored aspects of accuracy, consistency or ‘out’ shots, the trends here were consistent with expert players again maintaining a higher level of performance compared to the novice players. With respect to the exercise intensity main effect, the LSD post hoc analyses revealed highly significant differences between performance at rest and performance following high-intensity exercise. Additionally, highly significant differences were observed when performance following moderate and high-intensities were compared. In the main the analyses pointed to the fact that skilled performance at rest and skilled performance following moderate-intensity exercise were equivalent and in each of the analyses were not significantly different. Performance following high-intensity exercise however, was significantly poorer than that at rest and moderate-intensity exercise. Additionally, no exercise intensity by level of expertise interactions were observed. There is much consistency therefore across the basketball and tennis studies with respect to the way in which the expert and non-expert players perform under increasing intensity levels. As alluded to earlier, this finding was consistent across many analyses (accuracy, ‘in’ and ‘out’ percentages) conducted in the tennis study. In each case, the analyses revealed similar trends. In sum, across the studies exploring sports skills, expert players seemed to cope better across moderate and high-intensity exercise conditions. They were able to perform the respective skills at a higher level compared to the non-expert players. However, in both groups there are also consistent trends of a deterioration in performance with high-intensity exercise.

7.3 The effects of exercise intensity on coincidence-anticipation timing

The soccer, basketball and tennis investigations conducted as part of this work examined the effects of moderate and high-intensity exercise on sports skills. Among the possible explanations for the decline following high-intensity exercise were; (1) inhibition of the contractile processes of the key musculature, and (2) the inability of the specific muscle groups to cope with the demands of the task in terms of speed, accuracy or both. The subjective responses and observations of the researcher also seem to support this. However, with all skills, while the motor component of the skill is fundamentally important, it would be erroneous to suggest that the motor component is the overriding factor to consider in terms of successful completion of a particular skill. Sports skills are much more complex than the execution of a motor response (Allard, 1980). Furthermore, the way in which we process information greatly affects the outcomes of our actions and attention should also be given to the perceptual and cognitive elements of sports performance (Williams, Davids & Williams, 1999).

Savelsbergh et al. (2002) reinforce this point, adding that successful performance in sport requires skill in perception as well as the efficient and accurate execution of movement patterns. Ball games or fast-action sports, such as those examined as part of this work, also require rapid reactions and accuracy in anticipating the movement of a ball. In fact, the ability to accurately anticipate in sport has been highlighted as a major index of skill level (Tenenbaum, Sar-El & Bar-Eli, 2000). Other researchers deem that timing is by far the most important characteristic of bodily skill (Bartlett, 1958 as cited in Payne, 1986). McRobert et al. (2007) provide support for many of the latter points, citing that anticipation is a critical component of expert performance in sport, particularly in fastball sports.

In light of the findings of the basketball and soccer studies in particular, the third study conducted as part of this programme of research examined the effect of exercise at the same intensities on CAT in expert and non-expert Gaelic games players. The rationale for this is based on some of the latter points but also on some of the observed effects of exercise on performance in the basketball study particularly. One such observation was that, under high-intensity exercise conditions, players often failed to catch the ball cleanly (without fumbling) when it rebounded off the wall. Their timing or fluency of passing and movement was poorer and this was confirmed by the fact that the number of times the ball was fumbled increased following high-intensity exercise. CAT is an important underlying process responsible for success in movements such as catching (Payne, 1986). Furthermore, coincidence-anticipation has been suggested as an important underlying factor in externally-paced sports containing uncertainty (Singer et al., 1996). Soccer, basketball, tennis and hurling are all externally-paced sports containing uncertainly and so the results of the hurling study had implications for performance in each sport.

The sports in the initial investigations (soccer and basketball) all rely on coincidence-anticipation timing to predict the arrival of the ball, to catch, to intercept and so on. In tennis however, coincidence-anticipation timing is simply fundamental. The third study conducted here, focussed on a sport where CAT is one of the most critical skills in the game. Consequently, the sport of hurling was chosen. In hurling, CAT is important to almost all the skills of the game but fundamental in skills such as striking the ball at speed, blocking the ball and hooking an opponent's hurley. With respect to the interceptive task, a gross motor response was deliberately chosen as the studies up to this point also used gross motor responses. In terms of complexity, as with the other studies, the interceptive task according to Billing (1980) would be classed as a simple task. Ecological validity was again considered as much as possible and the interceptive task and design was developed through a series of pilot studies. With this study, scores were computed by means of three error scores (CE, VE and AE - all described in section 4.3.7). One remarkable finding of the hurling study was that in terms of CE (direction of error), no changes in performance were found either between or within the groups. In practical terms, this indicated that there were no differences or trends in terms of players anticipating consistently early or consistently late across exercise intensities. This finding is consistent with previous work conducted by Al-Nakeeb and colleagues (2005 & 2007). The results of the analyses conducted on the AE (absolute error) and CE (variability of error) showed the same significant findings and interactions. However, because AE combines both CE and VE to reflect the overall amount of performance error (Schutz, 1977), it warrants more emphasis and will be discussed at greater length here.

The repeated measures ANOVA on the AE error scores indicated that there was a significant exercise intensity by level of expertise interaction (p = 0.031). Therefore, as was the case in the basketball study, the findings of the hurling study also showed that there was an exercise intensity by level of expertise interaction. However, figures 15 and 20 reveal the nature of these interactions in the basketball and hurling studies and it is clear that they are very different. It has been highlighted already in chapter one that exercise effects on performance are very much dependent on the demands of the task used. This is a widely held view in the scientific literature. The tasks used in the soccer and basketball studies were both gross motor sports skills. The task in the hurling study was again a gross motor task but with a key timing element. In many respects, CAT combines both reaction time and movement time in one complete fluid movement. Therefore, the fact that the observed effects and interactions differ between the basketball and hurling studies is not altogether surprising because the basic requirements of the task are different.

Furthermore, the hurling study also revealed highly significant between-group differences ($p < 0.001$) showing that the non-expert players had higher AE scores than the expert players across all exercise intensities (Figure 20). The between-group analyses strengthen the argument that there are marked differences in terms of how experts and non-experts perform across exercise intensities. Experts seem to have the ability to maintain a higher level of performance across moderate and high-intensity exercise conditions and so the point by Janelle and Hillman (2003) is again supported by the findings of the hurling study. The issue raised by McMorris and Graydon (1996b) that expert players are better able to cope with physiological stress, is also supported by the findings of this work because the expert players maintained higher CAT scores across all exercise intensities.

Within-group differences in the expert and non-expert hurling player's data were analysed separately to explore group-specific differences across exercise intensities and explore other trends that may exist in the performance of these groups individually. The within-group analyses on the expert players CAT scores revealed no significant differences across exercise intensities ($p > 0.05$). There is much more consistency in the performance of the expert players across exercise intensities, which mirrors the findings of Al-Nakeeb et al. (2005) who also found no changes in AE in highly skilled performers across exercise intensities. Even so, the results seem quite contrary to those of Isaacs and Pohlman (1991) where AE deteriorated while cycling at VO_2 peak. Again, it is important to note that the nature of the exercise and interceptive task differed significantly and so the issue of task dependency is raised again. Tyldesley and Whiting (1975) conclude that there is an inordinate degree of consistency in the movement patterns displayed by skilled sports performers. The results of the expert players show this to be the case even when the movement pattern or CAT interceptive action is required immediately following moderate and high-intensity exercise. In the hurling study it appears that the activation brought on by this type of exercise task (running) stabilises the performance of the expert players. There seems to be continuity in terms of them being able to make a synchronised movement. This may relate, in part, to the fact that the exercise task used was specifically a general exercise task (running) while in the soccer and basketball studies a more anaerobic exercise task was chosen. This aspect of the present research is explored further in section 7.7. One interesting point regarding the non-expert players in the hurling study however, is the fact that their CAT improved following moderate-intensity exercise. Therefore, it could be construed that the general activation brought about as a result of the moderate-intensity exercise improved their CAT performance.

The consistency of the experts may also be explained by Meeuwsen, Goode and Goggin's (1995) suggestion that regardless of the complex sensory and motor processes involved in a CAT task, humans perform such tasks generally without much difficulty. It is possible therefore, that the interceptive task in this study, despite placing large sensory-motor and motor demands on the expert players, is so simple and familiar to them that they can still perform the task optimally when fatigued. Fleury et al. (1981) emphasised that the inter-dependence of the metabolic and perceptual systems was not seen in their study, nor in others they conducted (Bard & Fleury, 1978; Fleury, Bard & Carrière, 1981) on this topic. Al-Nakeeb and colleagues (2005 & 2007) also found this to be the case in their research. Fleury and colleagues suggested that physical exercise seems to leave the afferent pathways involved in this type of information-processing activity unimpaired. The findings of the experts are consistent with this view as no differences in CE, VE or AE were found in the expert players across all three exercise intensities.

The within-group analyses conducted on the non-expert players CAT scores revealed a significant main effect for exercise intensity (p = .016). The post hoc procedures revealed a highly significant (p = .009) improvement in performance following moderate-intensity exercise. Therefore, with the non-expert players, performance improved significantly following moderate-intensity exercise. It appears that the activation brought on by exercise at a moderate-intensity led to an improvement in the performance of the non-expert players. However, following exercise at a high-intensity, CAT performance returned to a level similar to their resting scores. Consequently, the results of the non-expert players are indicative of an inverted-U effect, with performance improvement following moderate levels of exercise and then a deterioration in performance following high-intensity exercise whereby performance returns to a level similar to their resting scores (Figure 20). The predictions proposed by Yerkes and Dodson (1908) seem to be confirmed by the hurling study, therefore. The within-group analyses for the non-expert and expert players show some common trends such as the lack of difference between performance at rest and that following high-intensity exercise. However, the significant improvement in performance following moderate-intensity exercise in the non-experts is not consistent with the expert players' scores. In fact, the improvement in performance within the non-expert players' scores is inconsistent with many previous studies conducted to date on this topic (Isaacs & Pohlman, 1991; Thomson, 2000; Al-Nakeeb et al. 2005; Al-Nakeeb & Lyons, 2007). Again, it is important to stress that in many of the latter studies the interceptive actions, fatiguing tasks and timing of CAT performance trials differed greatly to those in the hurling study. The interceptive task used in the hurling study as an example, is significantly different to any others reported in the scientific literature and so critical evaluation of the current findings with past research is more intricate. The significance of the findings of the hurling study with respect to the various theories of arousal is explored in subsequent sections.

The findings here to some extent, may be due to the fact that the exercise task was general as opposed to the localised exercise protocols used up to this point. Previous research (Al-Nakeeb et al., 2003) has revealed that localised muscle fatigue can have a more detrimental impact on motor performance than general forms of fatigue. Other studies involving cycling, running, and sprinting have provided evidence that compensatory mechanisms can be used to counteract the loss of the force-generating properties, which occurs when a muscle is fatigued (Rodacki, Fowler & Bennett, 2002). In other words, compensatory strategies may induce a reorganisation of the movement structure and a new coordination pattern may appear to counteract the losses in force which are experienced when fatigued. Such reorganisation of movement patterns may underpin the findings of the hurling study ork and provide some explanation for the lack of difference between performance at rest and that following high-intensity exercise in both the expert and non-expert groups.

Anticipation of coincidence contributes greatly to success in sports where predicting the arrival of a moving object is important (Molstad et al., 1994). In many sporting contexts, the anticipatory stage is essential in deciding what to do, initiating an effective response and moving quickly into the right place (Singer et al., 1996). In sport, the ability to quickly attach meaning to limited pieces of relevant information allows for greater anticipation of an opponent's actions. It also facilitates anticipation of the speed and location of an object as well as increased efficiency in responding to and dealing with a variety of aspects of sporting performance. Singer et al. (1996) also noted that attentional focus prior to and during movement has a great effect on overall performance. Therefore, the next section will explore the findings pertaining to the effects of exercise intensity on attention.

7.4 The effects of exercise intensity on attention

Attention is undoubtedly a key element of sports performance and is therefore imperative to success in the performance tasks conducted in the initial three investigations conducted on soccer, basketball and hurling. The importance of attention has been confirmed by commentators, coaches and players for some time. The ability to allocate and sustain attention to relevant information is crucial to the successful completion of both cognitive and motor tasks (Abernethy, 2001). Having assessed the psychological skills needed to perform effectively in sport, Janelle (2002) concluded that none is more critical than attention. This includes both the ability to direct attention where appropriate and also the ability to sustain an optimal attentional state and so its importance cannot be overstated. In the initial three investigations, maintaining appropriate attention during task performances was fundamentally important. In sport in general, maintaining focus or attention is often very difficult as almost anything can serve as a distractor. According to Bompa (2000) fatigue affects one's ability to stay focused and results in technical and tactical mistakes as well as throwing or shooting inaccuracies. In conditions of high emotionality or depleted cognitive resources, (e.g. intense exercise / fatigue states) individuals also express a greater tendency to redirect attention away from the central task and to irrelevant and potentially detrimental stimuli (Wegner, 1994). Desmond and Hancock (2001) support this view adding that fatigue states are associated not just with reduced attentional capacity but also with increased distractibility. The subjective responses provided by participants post-testing in the soccer and basketball studies provided some qualitative evidence that maintaining attention was difficult when players were required to perform under intense exercise states. No such observations were gained through feedback during the hurling and tennis testing sessions. In the case of the tennis testing sessions, the players very often observed that the testing conditions were difficult but also enjoyable. With some of the players in the tennis study, even when the testing became very challenging, they seemed to enjoy it, rather than be distracted by it, so attention did not seem to pose a problem.

The concept of attention is central to many of the theories of arousal but one in particular merits emphasis here. According to Nideffer's (1979) theory of attentional style, high arousal, which may be induced by high-intensity exercise, could lead individuals to focus on their perceptions of discomfort rather than on the task at hand. When participants become highly aroused, they display what he termed ‘a reduced attentional focus’ which results in poorer performances. Several authors have suggested that attention and cue utilisation may be fundamental to our understanding of the relationship between arousal and performance (Zaichkowsky & Baltzell, 2001). Therefore, for this reason, the Stroop study specifically set out to examine the effect of moderate and high-intensity exercise on attentional focus.

The results of the Stroop study can be seen in Figure 24 and it is clear that performance at rest and performance following moderate-intensity exercise are comparable. Subsequently, attention then deteriorates significantly following high-intensity exercise. The results suggest therefore, that moderate-intensity exercise impacts very little on attention beyond resting levels. However, as seen in many of the other studies high-intensity exercise leads to a deterioration in attention. The post hoc procedures revealed that there was a significant difference between performance following moderate and high-intensities, with no other differences evident. The number of errors was also analysed in this study but there were no differences across all conditions ($p > 0.05$). The decline in Stroop performance therefore is not due to participants making more errors, it is simply due to the fact that their speed of processing is reduced and so their overall Stroop times were reduced following high-intensity exercise. This deterioration in attention may underlie the decrements in performance observed in some of the other studies. The participant responses and subjective feelings often denoted this may be the case.

The findings of the Stroop study are consistent with some of the previous studies in the scientific literature. For instance, they support the findings of Hogervorst et al. (1996) where no differences in the number of errors made following moderate-intensity exercise was also found. However, Hogervorst et al. (1996) found a significant improvement in Stroop performance following moderate-intensity exercise (70% Wmax) which was not found in the present investigation. One study which is similar to the Stroop study conducted here, in terms of procedures and exercise intensities, is that of Miles and Roberts (1998). They also examined the effect of moderate (60%) and high-intensity (100% maximal exercise intensity) exercise on Stroop performance and found improved Stroop performance following moderate-intensity exercise as well as a decline in performance following high-intensity exercise. In percentage terms, the decline in performance from rest to high-intensity exercise was approximately 5% in the investigation conducted here. In the Miles and Roberts (1998) study, the decline in attention was as much as 12.3%. The reason underlying this difference may relate to the fact that high-intensity exercise was set at 90% of HRR in the present study whereas Miles and Roberts (1998) had participants exercise to their maximal intensity (100%). The physiological stress in their study should have been higher than that experienced in the present research therefore. There is consistency in the findings however, in so far as performance following high-intensity exercise declined to a level below that at rest.

Interestingly, the results of the Stroop study are not consistent with the view by Tomporowski (2003) that despite a fatigue state, the human body is capable of maintaining cognitive performance. The results are also inconsistent with empirical work conducted by Thomson (2000) and McGregor et al. (1999) although the protocols and tests of attention differ between the present work and theirs. One study which shows many methodological similarities to the present work is that of Al-Nakeeb and Lyons (2007) who examined the effect of fatigue at 50% and 80% HRR on attention (Stroop test). In their study, performance was measured during exercise at the desired intensities yet no difference across experimental conditions was found. The lack of difference in their results is similar to certain findings here, i.e. the lack of difference between performance at rest and that following moderate-intensity exercise. However, the deterioration in performance following high-intensity exercise in this study is not consistent with the findings of Al-Nakeeb and Lyons (2007). It seems significant that the criterion for high-intensity exercise in the current study was 90% HRR but in the work by Al-Nakeeb and Lyons (2007), 80% HRR was the criterion examined.

In terms of the different attentional processes, the results of the Stroop study are very interesting indeed. For example, the results provide no support for the predictions by Easterbrook (1959) and Nideffer (1979). Both of their theories predict results indicative of an inverted-U whereas the present results show no attentional narrowing or improvement at moderate-intensity and rather than performance returning to baseline following high-intensity exercise, it continues to deteriorate to a level below that at rest. The effects of high-intensity exercise on attention therefore seem more severe. The deterioration found following high-intensity exercise is also consistent with the view held by Tomporowski and Ellis (1986) that physical discomfort resulting from fatiguing exercise may result in performers focusing on their perceptions of pain rather than attending to the performance cues. In the Stroop study here, the deterioration in performance as a percentage was found to be 5%. When participants reach high-intensity exercise, there is often an internalising of attention as the participant focuses on the internal signals of pain and fatigue rather than upon the external stimuli (Salmela and Ndoye, 1986). The views of Salmela and Ndoye (1986) are consistent with the results found here. Furthermore, when internal attentional distractors or sensations, such as fatigue, are attended to and interpreted negatively there is an increased probability of a decline in performance (Lazarus, 2000). The Stroop study results provide some evidence that this may in fact be the case and it may also provide some clues as to why performance deteriorates at particular intensities.

7.5 Trends in the research findings

The different investigations have now been examined and so it may be pertinent at this point to identify trends in the research findings across the studies. The investigations on soccer, basketball and tennis examined the effects of moderate and high-intensity exercise on (gross motor) sports skills. With all three studies, repeated measures ANOVA found that overall, there was a significant exercise intensity effect. In the hurling and Stroop studies, exercise effects on a sport-specific interceptive task and attention were examined and again a significant exercise effect on performance was found in both. There is consistency, therefore, in the fact that exercise intensity significantly impacts on a player's ability to perform sport-specific skills, sport-specific interceptive tasks as well as one's attention.

In the soccer study, closer examination of the findings identified that two of the participants who had experience of playing at a semi-professional level performed more consistently following exercise at a high-intensity than the rest of the sample (collegiate level players). Given this, the scope of the work was broadened to examine whether exercise effects on performance were the same in expert and non-expert players. In the basketball, hurling and tennis studies, therefore, expert and non-expert groups were included and a number of exercise intensity by level of expertise interactions were found across the studies. All three studies showed that there are marked differences in terms of how expert and non-expert players perform across exercise intensities (Figure 15, 20 & 32). At a basic level therefore, firstly there was a trend towards exercise impacting significantly on the performance of players across the range of tasks investigated. With respect to exercise intensity by level of expertise interactions, these were limited to the basketball study and the absolute error analyses (hurling study) but it is also important to note that the nature of the interactions were very different.

In order to elucidate further on the findings, repeated measures ANOVAs with post hoc procedures were conducted in an effort to identify more specifically, the nature of these exercise intensity effects. The post hoc procedures revealed a number of trends. For example, in the soccer and Stroop investigations, performance at rest and that following moderate-intensity exercise were not significantly different (Figures 8 & 24). This was also consistent within the performance of the experts in the basketball, tennis and hurling studies (Figures 15, 32 & 20). It is clear therefore, that with expert players, no deterioration in sport-specific skills, CAT or attention was evident following moderate-intensity exercise. The results suggest that expert players at least are capable of tolerating moderate levels of exercise without any significant deterioration in performance. It is also important to add that a number of the analyses showed the same to be true of the novice players. For example, in the tennis study the novice player's performance was also equivalent at rest and moderate-intensity exercise. This is perhaps surprising given the range of physiological benefits that come with moderate-intensity exercise. Dickinson, Medhurst and Whittingham (1979) found that preliminary exercise increases general activation level and leads to a beneficial effect on performance. Moderate-intensity exercise also elicits optimal levels of CNS arousal (Chmura, Nazar & Kaciuba-Uścilko, 1994; McMorris & Graydon, 2000) which, among other performance indicators, improves reaction time. Åstrand et al. (2003) further add that moderate-intensity exercise is beneficial to performance due to increased blood flow, warming up of the musculature and increased speed of nerve transmission within the PNS. McMorris et al. (1994) add that these changes aid gross body movement and coordination, both of which would be required in the performance tasks here. More recently, Mohr et al. (2004) demonstrated the benefits of moderate-intensity exercise in terms of re-warming up prior to the second half of a football match. The authors highlighted that moderate-intensity exercise, or re-warming up led to players performing better physically but also having a greater degree of "readiness". To summarise, the beneficial effects of moderate-intensity exercise are many but the results of the various analyses conducted in this research show moderate-intensity exercise having little or no physiological or psychological effect on performance.

One trend that has emerged in this work is that regardless of the analyses, expert tennis players consistently performed better than their non-expert counterparts across all exercise intensities. In some instances the analyses revealed significant between-group effects (e.g. tennis and hurling studies) but in other studies (e.g. basketball) follow-up analyses revealed that the rate of decrement with increasing exercise was greater in the non-experts.

Undoubtedly however, the most consistent trend in the results across the experimental studies was the deterioration in performance following high-intensity exercise compared to resting performance. For example, in the soccer study, there was a significant deterioration in performance following exercise at a high-intensity compared to rest (Figure 5). In the basketball study, this difference or deterioration was highly significant and consistent in both expert and non-expert players (Figure 15). In the Stroop study, a non-significant deterioration in performance was evident (Figure 24). In the tennis study, a significant deterioration in accuracy was again exhibited across a number of analyses in expert and non-expert players. With the exception of CAT performance therefore, exercise at a high-intensity led to a decline in the performance of gross motor sports skills and attention. A deterioration in performance following high-intensity exercise has been commonly observed with respect to motor skills (Evans & Reilly, 1980; Went & El-Sayed, 1994; Al-Nakeeb et al., 2003; Royal, 2004) sport-specific skills (McGregor et al., 1999; Davey et al., 2002) and attention (Miles & Roberts, 1998; Bompa, 2000). However, while this deterioration has been commonly observed, the physiological reasons underpinning this decrement are ambiguous and extremely difficult to pinpoint.

As alluded to in section 1.4, the physiological causes, mechanisms or sites of failure have sparked much controversy and debate for many years. Multiple sites and etiologies have been argued and counter-argued. Given that the most frequently cited definitions of fatigue include “a reduction in force” as central to the definition, many authors have focussed on this aspect of the term. Numerous papers and review articles have been published relating to cellular mechanisms (Westerblad et al., 1991; Fitts, 1994; Myburgh, 2004), central mechanisms (Gandevia, Allen & McKenzie, 1995;

Davis & Bailey, 1997; Meeusen, Watson & Dvorak, 2006; Meeusen et al. 2006; Weir et al., 2006; Secher, 2007) and peripheral mechanisms (Fitts & Metzger, 1988; Enoka & Stuart, 1992; Bigland-Ritchie et al., 1995; Green, 1997; Vandenboom, 2004; Hunter, Duchateau & Enoka, 2004). In some papers, both peripheral and central mechanisms have been proposed (Green, 1990; Davis, 1995; Edwards, Toescu & Gibson, 1995; Gandevia et al., 1995; Jones, 1999; Åstrand et al., 2003; McKenna, 2003; Nybo & Secher, 2004). Different models have also been proposed (Noakes, 2000; St Clair Gibson et al., 2001; Noakes & St Clair Gibson, 2004) but as yet, there is no agreement or consensus of opinion on the different mechanisms or models. This is reinforced in very candid language by Ament and Verkerke (2009, 415) who state that 'exercise-induced fatigue is a poorly understood phenomenon'.

What is largely accepted today, however, is that the deterioration in performance evident with fatigue is unlikely to be linked to a singular disturbance or site (Lee, Becker & Binder-Macleod, 2000; Noakes, 2000; Hargreaves, 2008). Gandevia, Allen and McKenzie (1995) for example, highlighted that it would be biologically unsound if force production always failed because of an impairment at one step in this process. Subsequent authors have proposed that multiple sites are involved (Lee, Becker & Binder-Macleod, 2000). Evolutionary design dictates that multiple steps will tend to fail together but ultimately it is the CNS which may decide when enough is enough (Gandevia, Allen & McKenzie, 1995). Given that the focus of this programme of research was to examine the effects or consequences of fatigue in terms of sports performance, a review of peripheral and central mechanisms would be beyond the scope of this thesis.

Finally, when comparing performance under moderate-intensity exercise to that following high-intensity exercise the following trends were of note. Firstly, in the soccer study there was a highly significant deterioration in performance following high-intensity exercise compared to performance following moderate-intensity exercise (Figure 8). This was also evident in the tennis and basketball studies in the performances of both expert and non-expert players (Figures 15, 33 & 34). Consequently, the two studies examining the effects of exercise intensity on passing skills were consistent with respect to this aspect. The analyses in the tennis study were also consistent with this. In the Stroop study, a significant deterioration in attention was found following high-intensity exercise compared to performance following moderate-intensity exercise (Figure 24). This concludes the within-group analyses conducted across all four investigations.

The between-group analyses were more pertinent to the tennis, basketball and hurling studies, given the two distinct groups of players used in all three investigations. In each of these studies, the aim was to examine whether there are differences in terms of how expert and non-expert players perform across exercise intensities. Again, some consistent findings were evident across the studies. In each study, expert players performed marginally better than their non-expert counterparts across moderate and high-intensity exercise levels (Figures 15, 20 & 32). It is also true that some of these differences would not satisfy statistical significance but in sport, the margins separating winners and losers are often very small indeed and so these marginal difference are significant and worthy of future exploration.

Linked to this, in the basketball study, it is clearly evident that the rate of decline from rest to high-intensity exercise in the non-expert players (21.54%) is much greater than that in the expert players (10.8%). T-tests were conducted to identify if the rate of decline (Δ) was statistically significant and it was clear that the rate of decline from rest to 90% was significantly greater in the novice basketball players. Furthermore, the rate of decline from rest to 70% was also different. No change from moderate to high-intensity was observed however. The results highlighted that expert players do not experience the same decline in performance (Figure 15) as non-expert players thereby reinforcing the point by McMorris and Graydon (1996b) that expert players are better able to cope with physiological stress. Janelle and Hillman (2003) also hypothesised that experts may be more capable of dealing with affective states appropriately than non-experts so again, the results of the basketball study in particular provide a degree of support for this contention. However, it should also be noted that while experts were capable of better performances across exercise intensities, their performance still deteriorated under high-intensity exercise conditions. The findings of the basketball investigation are a clear demonstration of this.

In the case of the tennis study, again a number of analyses were conducted on the accuracy ‘in’ percentages and the ‘out’ percentages and in each case the expert players were capable of hitting groundstrokes consistently better than the non-expert players. Furthermore, this was clear across all exercise intensities. Examination of the data in Table 18 illustrates this. The tennis, basketball and hurling studies therefore, provided some evidence that there are differences between expert and non-expert players and how they respond and perform under fatiguing conditions.

7.6 Performance under moderate and intense exercise conditions – subjective responses

It has already been noted in section 2.2.4 that, along with the objective measures which form the basis of discussion here, participant judgements or subjective responses about test performances were also recorded by the investigator. The value of qualitative data obtained by participant judgements should not be underestimated, particularly with complex and multidimensional constructs such as fatigue (Arnett, 2002). This section, however, will focus on some of the points most frequently provided by the participants during their feedback to the investigator.

A number of participants in the soccer and basketball studies particularly, described the feeling of “having nothing left”, “weakness” or “no power” in their legs following the high-intensity exercise condition. This was also reported by some of the participants following the moderate-intensity exercise condition. The expression of “feeling empty” is often linked to a depletion of energy stores. It is also interesting that this point was not emphasised as much in the hurling, tennis or Stroop studies, where the fatiguing task comprised a more general running protocol. It may be therefore, that when exercise is localised in nature and when the muscle groups fatigued are also those used in the criterion task, that the impact of exercise is subjectively greater.

One observation recorded a number of times by the investigator was the fact that participants were often unsteady immediately following the fatiguing exercise or during the early stages of the performance test. It was also clear in some cases that there was a level of discomfort being experienced by participants which often led to a disruption in motor control. In terms of the performance tests conducted by the participants in the soccer and basketball studies, this effect was manifest in poorly directed passes, weak passes, poor ball speed or poor control of the ball. In the basketball study this was apparent through weak passes, fumbling the ball as it rebounded off the wall, or players stepping over the restraining line. The above errors in each case led to time penalties, thereby decreasing participants' overall scores. More specifically, in the basketball study, the number of times the ball was fumbled increased greatly following high-intensity exercise. Players' reactive skills to the ball rebounding off the wall were somewhat diminished following high-intensity exercise. At rest, few ball-handling errors were made but following both moderate and particularly high-intensity exercise the number of ball handling errors increased. An example of one such error occured when the players failed to catch the ball cleanly on its rebound from the wall and so fumbled the catch. Therefore, it may be that the deterioration evident in the soccer and basketball studies particularly is due directly or indirectly to the inability of the fatigued muscle groups to cope with the task demands or a decrease in co-ordination.

The final theme that emerged from the participant responses related to their difficulty in focusing entirely on the performance test under moderate and intense exercise conditions. For example, one participant highlighted "it was hard to concentrate completely on the test because your heart is pumping" or "it was really hard to focus on everything together, passing the ball, avoiding the cones and passing the ball in the zone like you said". The points here are representative of the range of subjective responses that were made by different participants concerning their difficulty in maintaining complete attention under intense exercise conditions. The number of times this was reported was unquestionably more frequent following high-intensity exercise in particular. The notion that fatigue states are associated with reduced attentional capacity and increased distractibility is not a new concept (Moran, 1996; Desmond & Hancock, 2001) but the points are intriguing and were explored more explicitly in the

Stroop study. The observations also reinforce points put forward by past researchers (Nideffer, 1979; Salmela & Ndoye, 1986) that high-intensity exercise can lead to a narrowing or internalising of one's attention, with participants focussing instead on internal signals of pain and the accruing fatigue. The result of this is that there is a lack of focus on external stimuli or the test performance. Attention in this case is inhibited leading to a decrement in performance. Although we cannot state explicitly whether attentional narrowing occurred, the results of the Stroop study provide confirmation in many respects that participants find it is difficult to maintain attention under high-intensity exercise conditions.

7.7 Localised fatigue versus general exercise effects

It has already been pointed out in the previous section that when exercise is localised in nature and the muscle groups fatigued are those used in the criterion task, the impact of the exercise is subjectively greater. It has also been hypothesised that the deterioration evident in the soccer and basketball studies following high-intensity exercise in particular, may be due to the inability of the muscle groups to cope with the task demands.

Among the earliest researchers, Cotton et al. (1974) investigated the effects of localised and what they termed 'total body fatigue' on gross motor performance. They concluded in their (1974) study that localised muscle fatigue was more detrimental to skilled motor performance than total body fatigue. Sanders (1983) has also argued that while physiological reactions to stress may be very similar, performance changes may differ for different stressors. Few studies similar to that conducted by Cotton et al. (1974) have been conducted since, but Al-Nakeeb et al. (2002) did examine the effect of high-intensity localised muscle fatigue (incremental arm ergometry to 90% HRR) on the performance of both fine and gross motor skills. Their results showed that high-intensity localised muscle fatigue had a significant detrimental impact on both types of motor tasks. Following on from this study, Al-Nakeeb et al. (2003) examined the effect of high-intensity localised muscle fatigue and high-intensity total body fatigue on gross motor performance. Localised muscle fatigue was developed using the same protocol (arm ergometry to 90% HRR) and in order to induce total body fatigue or general fatigue, a running protocol was used (incremental running to 90% HRR). Their results showed that high-intensity localised muscle fatigue had a detrimental effect on the performance of the gross motor task, but high-intensity total body fatigue did not. The findings of the latter study by Al-Nakeeb et al. (2003) mirror those of Cotton et al. (1974) and in some respects reinforce the claims of Sanders (1983) that different types of fatigue or stress may affect performance very differently.

The results of this programme of research provide evidence that high-intensity exercise utilising a restricted number of muscle groups leads to greater decrements in performance when compared to high-intensity exercise using general exercise modes (e.g. running). To reiterate, the deterioration in the soccer study from rest to high-intensity exercise, as a percentage was 7.9% and this was also statistically significant (p = 0.010). While the actual p value provides us with the most pertinent statistical information regarding the effects of the independent variable (in this case exercise intensity) on the dependent variable (task performance), many authors (Cohen, 1990; Thomas, Salazar and Landers, 1991) now propose that there is also a need to report some estimate of meaningfulness with all tests of significance. The one which has gained the most recent attention is effect size, originally proposed by Cohen (1969) where 0.2 or less is a small effect size, 0.5 is a moderate effect size and 0.8 or more is a large effect size. This gives us an indicator of how meaningful the treatment effect (exercise intensity) is. Therefore, reverting back to the soccer study, the effect size was .214. Simply put, this value (.214) illustrates that the effect size or practical significance was small.

In the basketball study the overall effect of exercise intensity was highly significant (p < 0.001) and the effect size was .711. This indicates that this exercise, utilising a restricted number of muscle groups (and therefore more localised) had a greater practical impact on basketball passing performance. In the basketball study, further analyses were carried out on the expert and non-expert players' data to explore exercise intensity effects within these groups separately. In the expert players, the deterioration from rest to 90% exercise as a percentage was 10.8% which was highly significant (p = .001) with an effect size was .538. In the non-expert players the deterioration from rest to 90% exercise as a percentage was 21.5% which again was highly significant ($p < 0.001$) and the effect size was .816. This indicates that the effect of exercise that is localised in nature on performance is high and constitutes a large practical effect. To summarise, localised fatigue protocols had a detrimental impact on the performance of the passing tests in both the soccer and basketball studies. The effect sizes however, vary from a small effect (soccer study), to a large effect (basketball study).

In the hurling and Stroop studies, more general exercise protocols (treadmill running) were adopted, and it is clear that the same level of deterioration is not evident. In the hurling study for example, the overall exercise effect was significant (p = 0.031) with an effect size of .176. This indicates that the practical effect of the general exercise on performance was small. Again, further repeated measures ANOVAs were carried out on the non-expert and expert players' data separately to analyse exercise effects within these groups. In the expert players the deterioration from rest to 90% exercise as a percentage was 9% but this was not statistically significant ($p > 0.05$). Therefore, general exercise at a high-intensity had no significant impact on the performance of the expert players. The non-expert players on the other hand, actually improved by 5.6% and this was statistically significant (p = 0.016). The effect size was .023. In the hurling study, therefore, the practical effect of exercise intensity on performance is small. The significant deterioration in performance evident in the basketball study for example, was not evident in the case of the hurling study. In fact high-intensity general exercise had no effect on the CAT performance of the expert players and led to a small but significant improvement in the performance of the non-expert players.

The analyses conducted on the 'in', 'out' and percentage data for the tennis study revealed a range of effect sizes that are presented in table 19. The effect sizes are low to moderate in general. Tables 19, 20 and 21 show this to be the case with no effect sizes that would be deemed large.

Finally, in the Stroop study, the repeated measures ANOVA revealed a significant overall exercise intensity effect (p = 0.018) with an effect size of .396 indicating that the practical effect of general exercise on attention was low to moderate. However, while there was a 5.3% deterioration in attention from rest to high-intensity exercise, this difference was not statistically significant. Therefore, there is some evidence in those studies that when protocols engage a restricted number of muscle groups and are therefore more localised in nature, the deterioration is more significant, with low to high practical effects. In the hurling, Stroop and tennis studies however, more generalised running/intermittent protocols were used and the effects of exercise on performance are not as large. The associated effect sizes are generally low also.

On closer inspection of those studies highlighted in chapter one, there is also further evidence that localised fatigue effects on performance are more pronounced than more generalised exercise protocols utilising running or cycling protocols. The more recent studies from 1990 onwards are summarised briefly and the effect of exercise on performance highlighted. The performance effect will be identified as either a significant improvement (↑), deterioration (↓) or no effect.

Table 23. Exercise effects on motor skills/ sports skills

Author(s)	**Modality**	**Exercise Protocol**	**Performance Effect**
Berger & Smith-Hale (1991)	Leg press station	Multiple leg presses at 60-80% of 1RM	↓ gross motor performance
Evans et al. (2003)	Arm ergometer	70% VO_2 peak	↓ shooting accuracy and Precision

(Table 23 Continued)

Apriantono et al. (2006)	Isokinetic dynamometer	Repeated loaded knee extension and flexion motions until Exhaustion	↓ quality of ball contact ↓ toe velocity before ball contact ↓ angular velocity of leg ↓ ball velocity
Squadrone et al. (1995)	Bow and arrow	6 X 10 rep static contractions 20s (shooting position)	No effect on shooting performance but a significant increase in lateral sway
Davey et al. (2002)	Test performed on a tennis court	Intermittent tennis test to volitional exhaustion	↓ in some but not all shots
Went & El-Sayed (1994)	Cycle ergometer	85% VO_2 max	No effect on gross motor Performance
Hoffman et al. (1992)	Cycle ergometer	100% maximal work Capacity	No effect on shooting performance
McMorris et al. (1994)	Cycle ergometer	100% MPO	No effect on soccer passing
Royal et al. (2006)	Swimming pool	181 bpm, RPE 19+, blood lactate 7+ mmol	No effect on shooting accuracy or ball speed

From the studies described here, there is at least some evidence that many of the more general exercise protocols involving for example, cycling at high percentages of VO_2 max did not impact on performance of the different tasks. However, localised protocols for the most part led to a significant deterioration in some or all aspects of performance. If those studies examining exercise effects on attention are examined, then the following results are evident:

Table 24. Exercise effects on attention

Author(s)	Modality	Exercise Protocol	Performance Effect
Hogervorst et al. (1996)	Cycle Ergometer	75% of max work Capacity	↑ Stroop performance
Miles & Roberts (1998)	Cycle Ergometer	100% max work Capacity	No effect on timed Stroop performance but ↓ accuracy
Thomson (2000)	Treadmill	Not provided	No effect on performance
McGregor et al. (1999)	Treadmill	Intermittent shuttle running	No effect on performance
Al-Nakeeb & Lyons (2007)	Cycle ergometer	80% HRR	No effect on performance

The studies outlined here, all employ general exercise / fatigue protocols involving running or cycling at percentages of maximal work capacity or heart rate reserve. No studies were found evaluating localised fatigue effects on attention and so this cannot be evaluated here. However, it is clear that the majority of studies point to no significant decrement in attention. Miles and Roberts (1998) however, did find a decrement in Stroop accuracy following exercise at 100% maximal work capacity. It is also interesting that this is the highest intensity of all the studies cited here. It seems therefore, that when general exercise or fatigue protocols are adopted, little or no deterioration is evident. However, it may be that if the intensity reaches maximal levels a deterioration in performance is more evident.

Finally, with respect to CAT, most of the studies by Fleury and Bard prior to 1990 (Bard & Fleury, 1978; Fleury, Bard & Carrière, 1981; Fleury et al., 1981; Fleury & Bard, 1987) found no effect of exercise / fatigue induced using running or cycling protocols on AE. With reference to those studies conducted after 1990, the following results are evident:

Table 25. Exercise effects on CAT

Author(s)	Modality	Exercise Protocol	Performance Effect
Isaacs & Pohlman (1991)	Cycle ergometer	VO_2 peak	↓ in CAT performance
Al-Nakeeb et al. (2005)	Rowing ergometer	90% HRR	No effect on CAT performance in low or high skilled performers
Al-Nakeeb & Lyons (2007)	Cycle ergometer	80% HRR	No effect on CAT performance

Once more, the results show that general exercise / fatigue protocols for the most part impacted little on performance. What is evident from the results of this programme of study and the trends observed in the literature is that localised muscle fatigue seems to have a much greater impact on performance than the more general or total body fatigue protocols (e.g. running and cycling). With the general forms of exercise, deterioration in performance is not common although some exceptions are highlighted. When a deterioration in performance is found, it tends to be in cases where the intensity is maximal.

If one considers the range of other studies examined in chapter one, where localised muscle fatigue protocols were employed the trend continues. Many of these protocols inducing localised muscle fatigue were outlined in table one. However, the results of these studies show a high degree of consistently in that localised muscle fatigue impacts negatively on the range of tasks examined. For instance, significant deterioration in proprioception (Voight et al., 1996; Pedersen et al., 1999; Forestier, Teasdale &

Nougier, 2002, Al-Nakeeb, Lyons & Nevill, 2004; Francisco et al., 2007; Venancio et al., 2007), motor control (Johnston et al., 1998), balance (Yaggie & Armstrong, 2004), postural control (Vuillerme, Nougier & Teasdale, 2002) and vertical jump performance (Smilios, 1998; Rodacki, Fowler & Bennett, 2001 & 2002) have been found. It is important to note that all of these performance components are fundamental to success in sport and so the results of these studies are very much pertinent to practitioners of sport. It is important at this point to outline that the aim of this section is not to digress from the performance components examined as part of this work but instead strengthen the argument that localised muscle fatigue has a more detrimental impact on performance than general fatigue. Meta-analytic techniques are needed here to evaluate the point in greater depth.

Physiologically, it is difficult to identify why localised fatigue protocols lead to a more significant deterioration in performance than general running or intermittent protocols as was used here in the tennis study. A decline in performance after localised muscle fatigue may be the result of (a) a change in co-ordination (b) a change in the functional capacity of the muscles to produce force or (c) the combination of these two factors (Rodacki, Fowler & Bennett, 2002). Bangsbo (1994) also added that the reduction in muscle force owing to fatigue is likely to be due to a decrease in the number of fibres that can be recruited to generate force as fibres already recruited begin to fail. Whether fatigue induced by general running or cycling protocols leads to the same changes is questionable. Instead, it could be postulated that when fatigue is induced using running or cycling protocols, participants may actually benefit from some of the physiological benefits highlighted in the previous section. These include an increase in blood flow, an increase in the speed of nerve transmission and a general warming up of the muscles (Åstrand et al., 2003), increased speed of muscle contraction (Mohr et al., 2004) or an increase in general activation (Dickinson, Medhurst & Whittingham, 1979). These benefits may provide at least some of the underpinning reasons why the general fatigue protocols, for the most part, impact less on performance. With the localised muscle fatigue protocols, however, it is unlikely that these benefits are experienced because the duration of the fatiguing task is often very short. For example, the localised fatigue protocols used in this programme of research were all completed within one minute and whether this is sufficient time to experience a general warming up of the muscles as an example, is unclear.

To sum up, it is clear from the results of the empirical work conducted as part of this programme of research that the more localised protocols at a high-intensity led to statistically significant decrements in performance, with effect sizes ranging from low-to high. With the more generalised protocols however, a decline in performance was not evident in some cases (e.g. the hurling study). In fact, in the case of the latter study, the contrary was found to be the case in the non-expert players. Furthermore, in the Stroop study, there was no significant decrement from rest to high-intensity fatigue, with practical effects ranging from low to moderate. Effect sizes in the tennis investigation once more revealed low to moderate effects. Localised muscle fatigue therefore, seems to have a more debilitative effect on sports performance than general fatigue. In the next section, this will be explored in terms of the theories of arousal but with particular reference to McMorris and Graydon's (1996b) views regarding maximal effort and homeostasis.

7.8 Theories of arousal

One of the aims of this programme of research as outlined in section 1.10 is to explore whether the main theories of arousal in the scientific literature support or underpin the findings of the studies conducted here. It has already been highlighted that, while exercise induces physiological and biochemical changes which are similar to those induced by arousal, the effect may not be entirely synonymous. McMorris and colleagues (McMorris & Keen, 1994; McMorris & Graydon, 1996 & 1997) have also expressed concerns over whether these theories, based largely on the effect of emotionally-induced arousal, also explain or predict the effect of exercise-induced arousal on performance. Despite these concerns, authors today continue to explain the findings of their research examining exercise / fatigue effects on sports performance, in terms of these theories of arousal. The following section will discuss the merits of these theories relevant to the range of results collated here.

The first theory of arousal explored in section 1.6.1 was the inverted-U theory developed by Yerkes and Dodson (1908). The results of the soccer study partially satisfy the predictions of the inverted-U theory. For example, performance was optimal following moderate exercise intensity levels, which supports the claims of Yerkes and Dodson (1908). However, there was a significant deterioration in performance following intense exercise compared to resting performance which is not consistent with inverted-U theory. The soccer and tennis studies revealed trends more consistent with an inverted-J effect as there was improved performance following moderate levels of exercise but then deterioration following high-intensity exercise to a level below that at rest. With respect to the basketball study, the results of the non-expert players are quite contrary to the predictions of inverted-U theory since performance progressively deteriorated as exercise intensity increased. The results with respect to the expert players however, vaguely resemble an inverted-J effect, as there was no deterioration following moderate-intensity exercise but a significant deterioration following exercise at a high-intensity, again to a level below that at rest. Nonetheless, in the hurling study the results of the non-expert players are consistent with inverted-U theory. The non-expert players demonstrated a significant improvement in performance with moderate-intensity exercise but when exercise or arousal level increased to a high-intensity, performance dropped to a level similar to that at rest (Figure 20). With the expert players in this same study, the lack of difference between rest and performance following high-intensity exercise is consistent with Yerkes and Dodson's (1908) theory but the slight deterioration in performance following moderate-intensity exercise is not.

Finally, in the Stroop study the results revealed trends more consistent with an inverted-J effect. In this study, there was a negligible improvement in attention following moderate-intensity exercise levels, but then deterioration in performance following high-intensity exercise to a level below resting performance level. This is very similar to those results found in the soccer study and the results of the expert players in the basketball study. In summary therefore, with the exception of the CAT scores of the non-expert players in the hurling study, the results of the range of studies conducted as part of this programme of research are not consistent with the predictions of inverted-U theory. There is however, some consistency in so far as performance following high levels of exercise / fatigue led to a decline in performance to a level below that at rest.

The inverted-U theory is frequently reformulated in term of underlying attentional mechanisms. Tomporowski and Ellis (1986) believed that the inverted-U theory could be explained by Easterbrook's (1959) cue utilisation theory which shares many common characteristics with Nideffer's (1979) theory of attentional and interpersonal style. McMorris and Graydon (1996b) add that the most commonly used explanation for the effect of arousal on performance is that arousal affects attention. In this programme of research, no direct measure of cue utilisation was possible but the Stroop study attempted to explore the effect of fatigue or arousal on attention (Stroop performance). This study sought to examine the two most fundamental aspects of Easterbrook's (1959) theory. Firstly, is performance optimal at moderate arousal level as attention focusses on task-relevant cues only? Secondly, at high levels of arousal, does attention narrow so much that task-relevant cues are missed and thus, performance returns to baseline levels? The first finding of the Stroop study was that moderate exercise or arousal did not improve attention and so this is inconsistent with the claims of Easterbrook (1959). There is also consistency in that, following high-intensity exercise, attention deteriorated to a level that was equivalent to that at rest.

What the stroop study is unable to identify explicitly, however, is whether the deterioration found at a high-intensity is in fact due directly to attention narrowing. It would be naive to suggest that this is certainly the case. Tomporowski and Ellis (1986) suggested that physical discomfort resulting from fatiguing exercise may result in performers focusing on their perceptions of pain rather than attending to the performance cues, a claim first proposed by Nideffer (1979). The Stroop study results may be explained by this hypothesis. Salmela and Ndoye (1986) referred to this as 'the internalising of attention' emphasising that the participant focuses on the internal signals of pain and fatigue rather than upon the external stimuli. These points may explain the results found here. Information provided by the participants in some of the other studies conducted as part of this programme of research show that there may be merit in these hypotheses. For example, in the soccer and basketball studies players in the debriefing sessions frequently revealed that following the fatiguing exercise they felt that the strength / power in their legs was “not there” or they had “nothing left” in their legs. In the soccer study it was also shown that more errors were made following fatigue at a high-intensity, an observation that may be related to the points made already by Salmela and Ndoye (1986) or Tomporowski and Ellis (1986). It is very possible that with high-intensity exercise or fatigue, attention may shift towards the sensations of fatigue, more errors in performance occur and inevitably, performance deteriorates. The results found in both the soccer and basketball studies provide indirect support for this view.

The second major theory of arousal that was examined in section 1.6.3 was that of drive theory. This theory derived from the work of Hull (1943) some of whose observations are borne out by the findings of this research. For example, high levels of arousal do not always result in poor performance, although sometimes this is the case (Hull, 1943). The results of all five studies conducted in this work show this to be true. This research has shown that high-intensity exercise or arousal impacts negatively on some tasks (e.g. passing skills) but very little on others (CAT). Furthermore, Hull observed that moderate levels of arousal do not always result in better performances as hypothesised in inverted-U theory. Again the results of the basketball and tennis studies and the expert players’ results in the hurling study, support this view. However, it is the case also that some of Hull’s predictions are not supported by the research findings. For example, there is a positive relationship between arousal and performance, when a task is well-learned with strongly formed habit patterns (Hull, 1943). Therefore, a high level of arousal would be desirable for optimal performance in these types of tasks or skills. In the basketball study, the passing task chosen involved chest passing a basketball 2.44m against a target measuring 61cm by 61cm. For the expert players in particular, this test or skill would be very simple indeed. The same was true of the task in the tennis study. For the expert players at least, hitting tennis groundstrokes was very simple and a well-learned skill. Many of the players were playing tennis three times a week and playing two or three competitive matches a week. Despite these points, significant deterioraton was found in the performances of the expert players with high-intensity exercise. In spite of this, high arousal or intense exercise led to a significant deterioration in passing performance. In fact, the results of the expert players in the basketball study are a complete contrast to the predictions of Hull (1943) when a task is well-learned.

Few studies have supported the predictions of drive theory, specifically that excessive arousal often disrupts performance (Martens, 1971). The results of the investigations in this program of research largely support the point that high levels of arousal lead to a decline in performance. In the soccer study, as an example, more passing penalties were incurred at the highest exercise intensity, overall time penalties increased resulting in a general deterioration in performance. The number of 'out' shots increased in the tennis study during intense exercise and this was consistent in expert and non-expert players. If the fatiguing nature of the intermittent task in the tennis study and the resulting high heart rates and RPE values can be taken as evidence that arousal levels were elevated, then perhaps the findings in this study and others are indicative of the fact that excessive arousal disrupts performance. This disruption was also evident in the basketball and Stroop studies.

The second model proposed by Hull (1943) related to how arousal affects performance when a task is not well-learned. In this case, Hull (1943) believed that increases in arousal would either have no effect on performance or lead to deterioration in performance. Interestingly, there is more support for this view in the context of this research. For example, in the case of the Stroop study, the performance task chosen was novel and so not well-learned. In this study, an initial improvement in performance was evident with exercise and then further increases in exercise intensity led to a significant deterioration in performance from the 70% intensity to the 90% intensity. Therefore, the results of the Stroop study show that there is some merit in Hull's (1943) theory when a task is not well-learned. Likewise, in relation to the tennis study, there is also some evidence of this (Figure 33). The non-expert players in this case may not have been accustomed to having to hit the tennis ball to a $2m^2$ area marked out on the court. The findings illustrated in Figure 33 provide some evidence at least, that Hull's (1943) claims may have merit when a task is not well-learned.

Authors such as Yerkes and Dodson (1908) and Oxendine (1984) have long since identified that the effects of exercise on performance vary depending on the nature of the task completed. This point was outlined in chapter one and the results of the various studies completed in this work lend support to this claim. Oxendine (1984) for example, theorised that if a task was complex, moderate levels of arousal would result in optimal performance, while high levels of arousal would cause a deterioration in performance. However, if the task was simple then it would require high levels of arousal for optimal performance to be exhibited. Despite this, there is still a problem of defining what constitutes a 'simple' and 'complex' task (Zaichkowsky & Baltzell, 2001). Billing (1980) addressed the issue suggesting that task complexity should be based on information-processing demands and the complexity of the motor response. Using this framework, motor tasks requiring attention, judgement, discrimination and fine motor control would be classed as complex and so would be best performed under low or moderate states of arousal. However, motor tasks requiring strength, endurance, speed or ballistic movements would be classed as simple tasks and thus, require higher levels of arousal for optimal performance. Oxendine (1984) also supported the view by Hull (1943) that there is a linear relationship between arousal and performance for simple tasks or gross motor activities involving strength and speed. These types of activities according to Oxendine (1984) are typically well-learned, with strongly formed habit patterns. Therefore, a high level of arousal would again be desirable for optimal performance in these types of skills as increases in arousal should enhance the probability of making the dominant response. With reference to the tasks used here, according to Billing's (1980) classification, the tasks in the soccer, basketball, tennis and hurling studies would be classified as simple as they all involve speed, strength and largely ballistic movements. The tennis study however, may be the exception here particularly with respect to the motor element. However, this task was simplified by keeping a consistent feed (from the ball serving machine) in terms of speed, spin and length. With this in mind, it is clear that the results of the soccer, basketball, tennis and hurling studies are not consistent with the views of Oxendine (1984). In all of these studies, there was either a significant deterioration in performance with high levels of fatigue or no change in performance, yet for the most part, performance was not optimal at high arousal levels.

It would appear, therefore, that the arousal theories here cannot by themselves account for the findings of this research. While some of the findings undoubtedly support the predictions of the inverted-U theory (Yerkes & Dodson, 1908), there are arguably more examples where the findings do not. The predictions of drive theory (Hull, 1943) are not supported when a task is well-learned although there is more support for the predictions of Hull (1943) when a task is not well-learned. The view by Martens (1971) that excessive arousal disrupts performance is largely borne out by the results of the soccer, basketball and Stroop studies. The Stroop study showed that there is consistency between the findings of this study and the predictions of Easterbrook (1959) and Nideffer (1979). What is unclear however is whether the deterioration found at a high or fatiguing exercise is definitely due to attention narrowing or increased distractibility? This needs further examination. Finally, the results of this programme of work provide evidence to support the claims of Oxendine (1984) when tasks are complex but contradict Oxendine's predictions when simple tasks are performed under differing levels of arousal.

The lack of agreement between the findings of the studies conducted as part of this research and the various theories of arousal is not surprising, however, for reasons highlighted earlier. McMorris and colleagues (McMorris & Keen, 1994; McMorris & Graydon, 1997b) stated that exercise is undoubtedly a stressor and will affect arousal level, but possibly in a different way to emotionally-induced arousal. They continue that it is possible that maximal intensity exercise may not produce very high levels of arousal and, therefore, equating maximal exercise with maximum level of arousal, is questionable. McMorris and Graydon (1996b) add that exercise may have to go beyond maximal effort, into a zone where homeostasis can no longer be maintained, before a decrement in performance is observed.

The final point worthy of consideration, is that arousal is a non-unitary concept and there are complex interactions between arousal and several multidimensional psychological concepts such as motivation and attention (Brisswalter, Collardeau & René, 2002). The optimal level of arousal for a particular task is dependent on many factors that are unique to the individual (Landers & Arent, 2001). The arousal-performance relationship is primarily meditated by (1) task complexity, (2) skill level of the performer, and (3) personality differences (Zaichkowsky & Baltzell, 2001). The results of this programmer of research support some of these generalisations but more research is certainly warranted.

7.9 The multidimensional allocation of resources theory

It is clear that no single theory of arousal accounts for the findings of this work. The problems regarding the theories have already been discussed and one issue, undoubtedly, is that these theories are unidimensional. Past researchers (Kahneman, 1973; Pribram & McGuinness, 1975; Sanders, 1983; Humphreys & Revelle, 1984) have criticised these theories as being too simplistic and not reflecting the complex nature of the concept of arousal. As a result of this a number of more recent authors (Delignières, Brisswalter & Legros, 1994; McMorris & Graydon, 1996a, 1996b, 1997a and 1997b) have instead focused on multidimensional theories.

Kahneman (1973) introduced the notion that performance is affected by arousal and what he termed cognitive effort. Arousal refers to the amount of resources available to the CNS, whereas effort is responsible for the allocation of these resources. According to Kahneman, arousal is the physiological and biochemical response to stress and results in increases in CNS resource levels, which he called allocatable resources. In other words, as arousal rises there are more resources available to the individual. The key here however, is how these resources are allocated; this is the role of cognitive effort. Kahneman claimed that even at low levels of arousal, it is possible for cognitive effort to allocate resources to task-specific information with the end result that performance does not suffer, it can remain optimal. He stated that at high levels of arousal however, which is being hypothesised in this work to occur following the intense exercise protocols, it was impossible for effort to totally overcome the negative effects of arousal. In this case optimal allocation of resources becomes very difficult. According to Kahneman therefore, performance when arousal is high will be less than optimal as cognitive effort cannot focus attention solely on task-relevant information.

The findings across the studies conducted in this program of research show consistency with this latter view. In the soccer, basketball and tennis studies, following intense exercise there was a significant deterioration in performance. This deterioration in the performance may link to the predictions of Kahneman (1973) as players are unable to focus attention solely on task-relevant information. This deterioration was experienced in expert, novice, male and female participants alike.

Throughout the course of this research a range of information was collated from participants regarding subjective feelings about the testing, their thoughts as they were performing the tasks, what they felt locally in the working muscles and what they felt globally. These subjective responses provide some insight into the fact that some participants across the testing sessions did struggle to focus all their attention on the performance task. For example, one participant fed back that ‘it is hard to concentrate on everything as you are trying to pass the ball [and at pace] and then move around, controlling the ball without touching the cones…its hard to concentrate on everything’. It is clear from the point here that under intense exercise conditions, players struggle to attend to the task at hand, i.e. the performance task. Therefore, increased distractibility in this form was a feature of the performance of participants across moderate but more pertinently following high-intensity exercise. It is certainly the case that these responses were more frequent in the intense or high-intensity bouts.

In their processing-efficiency theory, Eysenck and Calvo (1992) distinguish between performance effectiveness, which refers to the quality of task performance, and processing efficiency, which refers to the product of performance effectiveness divided by effort. Effort is determined by the amount of processing resources invested in the task. Although this model may have much relevance and application to the findings here, the quantification of ‘effort’ according to Graydon (2002) remains a major stumbling block with respect to processing-efficiency theory.

Processing efficiency theory therefore, in its simplest form holds that, when confronted with anxiety-inducing circumstances such as would be the case here at high-intensity levels, the efficiency by which information is processed and acted upon decreases, potentially resulting in performance decrements (Janelle, 2002). Therefore, while performance may remain similar in high-anxiety compared to low-anxiety circumstances, the individual is required to work harder in the high-anxiety conditions to maintain performance. In this case, while performance effectiveness is being maintained, performance efficiency is impaired. In some cases, performance may actually improve when one is anxious due to the motivational aspects of anxiety that allocate additional resources for task performance. This may link to some of the observations in the tennis players where they often exerted additional effort as the performance test started to get more difficult or even very difficult.

Eysenck and Calvo (1992) also claimed that, even at high levels of arousal, performance can be optimal if effort allocates resources to the task. This will only happen however, if the task is well learned and will be at the expense of processing efficiency. Again over the course of this program of research a number of study findings are consistent with this view. For example in the Hurling study, little or no performance changes were observed in the expert or novice players for that matter. If the predictions of Eysenck and Calvo (1992) are true then it may be that with efficient or appropriate attentional allocation, performance can remain at an optimal level even in intense exercise conditions, a view consistent with the predictions of Kahneman. In the case of the tennis study, one observation the researcher made was that some of the players as the intensity increased actually started to hit the ball harder and challenge themselves some more. Some players started to really ‘go for shots’ often increasing the pace on the shot. Likewise, in the hurling study, the expert players did not experience a deterioration in performance at high-intensity fatigue, possibly due to players channelling extra resources (physical and mental) towards the task. Whether this is due to increased physiological effort, attention, additional resource allocation however, is unclear.

There is further evidence in the scientific literature (Delignières, Brisswalter & Legros, 1994) in support of this contention. Observations of competitive sport also provide frequent examples of this effect where players often have huge motivation to perform well under intense exercise / arousal states. These motivations come in many different forms, stimulated by feelings of anger, possible financial rewards, titles or trophies. All of these serve to motivate players to invest more effort as they strive to compete or perform at the highest level possible.

In this work, the motivation of the participants was not assessed in the initial investigations but was considered in the design of the tennis study. The players who exhibited high approach achievement motivation, therefore, would be considered highly motivated. High on approach, as assessed using the AGQ-S, indicates a desire and motivation to perform as well as one can and to be better than others. According to Eysenck, highly motivated players such as these should be able to perform optimally even under high-intensity exercise/fatigue conditions (or when highly aroused). However, this was not found to be the case since across the range of analyses conducted in the tennis study relating to the achievement motivation scores, the performances of the high approach group deteriorated following high-intensity fatigue. Another view is that one would assume that the expert players in the basketball, tennis and hurling studies would be regarded as highly motivated. All these performers were playing their respective sports at a high level, all were playing matches each week and training multiple times every week also. These points, added to the fact that all players willingly volunteered to participate, suggest that the performers are highly motivated yet performance decrements were still evident. The decrement of course could be due purely to physiological aspects linked to chemical, muscular or neuromuscular changes. While many of the changes in performance in this work are clearly observable the mechanisms underlying the changes are difficult to pinpoint. It is the case in this research that many of the observations therefore and performance changes are consistent with the predictions of Kahneman (1973). More research is needed however, to validate the predictions and isolate the mechanisms involved.

In summary, the range of studies conducted in this work provide a large degree of support for the predictions of Kahneman (1973) and the multidimensional allocation of resources theory. Kahneman’s (1973) proposal that as arousal increases there are more resources available to the individual seemed to be borne out in the observations made by the investiagator but also in the performances of the players. How the performer allocates these resources is clearly fundamental and again this may link to why so much variation in performance was observed over this program of research. In the soccer, basketball and hurling studies, there is indirect evidence to support many of the contentions of Kahneman. Kahneman postulated that, even at low levels of arousal, performance can be optimal with optimal allocation of resources to the task. Again there is evidence of this in the findings of the basketball and tennis studies, in particular, but also in the expert players' data in the hurling study. Thirdly, with respect to the issue of expertise, Kahneman stated that at high levels of arousal, non-expert players will not be able to focus attention solely on task-relevant information and so performance will deteriorate. Again this is supported in the soccer, tennis and basketball studies but not in the hurling study.

The fact that there is not complete support for all the predictions of Kahneman (1973) across all studies is not surprising given the complexities associated with this topic. Many of these have already been outlined in section 1.3. Clearly however, Kahneman's (1973) model seems the most pertinent one in the context of this programme of research. What is fundamental is the range of potential contributing factors that have not been measured in this work, some of which may impact on this relationship. One factor, already discussed, is the type of fatigue being experienced which may impact on the resulting arousal level. The type and complexity of the task being performed is also a fundamental consideration. The expertise of the individual and how well-learned the task is also important. Whether any one model will adequately explain the effects of fatigue or arousal on performance given the complexities already mentioned, as well as the other contributing factors, is a question that remains. The findings here illustrate that Kahneman's (1973) theory has merit and future research may be warranted to examine some of the finer details of this theory with respect to task complexity, expertise and attention.

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions of this research

In the past 350 years, over 30,000 manuscripts have been written on the factors that cause fatigue (Abbiss & Laursen, 2006). This point alone serves to highlight the huge role that this state plays in sport, transportation, ergonomics and industry. According to Bompa (2000) in sport fatigue is the most detrimental factor to performance. Also, the importance of fatigue in sport has been confirmed by a host of people ranging from players, coaches, managers and commentators alike. In soccer, five review papers have been published within recent years relating to match play demands and fatigue in the sport (Mohr, Krustrup & Bangsbo, 2005; Stølen et al., 2005; Bangsbo, Mohr & Krustrup, 2006; Bangsbo, Iaia & Krustrup, 2007; Reilly, Drust & Clarke, 2008). Astonishingly however, very little research has examined the effect of fatiguing exercise on the performance of sport skills (McMorris, 2004) despite its obvious importance. The fact that the issue is fraught with complexity accounts for the paucity of research. However, it is this very complexity which makes the topic intriguing and stimulating for psychologists, physiologists, sport scientists and biomechanists.

The main aims of this work were to examine the effect of both moderate and high-intensity fatigue on sports performance. As the work developed, the scope of the work expanded to examine whether the effects of fatigue on performance were the same, regardless of level of expertise. The work also sought to explore whether the findings of this work could be explained by the main theories of arousal. This is certainly a challenging aspect here due to the difficulties in empirically examining the theories in a sporting context. The quantification of ‘effort’ as an example, according to Graydon (2002) remains a major stumbling block with respect to processing-efficiency theory.

The conclusive findings of this research suggest that high-intensity or intense exercise leads to a significant deterioration in the performance of sport skills and a decline in attention. The view by Martens (1971) that excessive arousal disrupts performance, was shown to be the case here. This work also showed that exercise / fatigue effects on performance are different in expert and non-expert players. Expert players in many instances performed at a higher level than their non-expert counterparts, or the rate of decline in their performance was less. Further research is warranted here as the existing literature relating to expert and non-expert performances under exercise conditions is limited.

In keeping with the findings of many past studies (Fleury & Bard, 1987; Fleury, Bard & Carrière, 1981; Al-Nakeeb et al., 2005; Al-Nakeeb & Lyons, 2007) this research found that intense or fatiguing exercise does not impair CAT performance. This point also served to highlight the fact that exercise and fatigue effects on performance are different, depending on the task performed and in particular the complexity of the task. The hurling study also provided some evidence that fatigue is a transient state and its effects may only last for a short period of time. In the hurling study, there was evidence that some recovery may take place if the duration of task performed post exercise state is too long. This finding vindicated in some respects the modifications made in each study to ensure that performance tasks were completed within thirty seconds.

In the case of the tennis study, gender differences and differences according to ones achievement motivation were also analysed. These analyses were exploratory in nature and simply put, no differences of significance were found. The tennis study however, provided evidence that the effects of moderate and intense exercise on performance are the same regardless of gender, in fact very similar trends emerge in both groups. The second part of this work attempted to explore whether the findings of this work could be explained by the main theories of arousal. The results indicated that the theories of arousal cannot by themselves account for the outcomes from this work. The theories of Hull (1943) were not substantiated when a task is well-learned although there is some support for Hull’s predictions when a task is not well-learned. The findings of the Stroop study were consistent with the predictions of Easterbrook (1959) and Nideffer (1979) in terms of the impact of arousal on attention. However, while the predictions are confirmed, the mechanisms are unclear. The claims of Oxendine (1984) with respect to task complexity again show inconsistent trends. The lack of agreement between the findings of this research and the various theories of arousal, however, emphasise further the point by McMorris et al. (1999) that the relationship between arousal and fatigue needs to be explained better than simply pointing to similarities in the physiologic symptoms shown by both types of arousal. This point undoubtedly accounts for the lack of agreement found here. The results, however, provide a large degree of support for the predictions of Kahneman (1973) and his multidimensional allocation of resources theory.

In sport, the difference between winning and losing is often minuscule. For athletes, trainers and players, understanding those variables that limit performance and identifying variables that can or cannot be changed is fundamental in ensuring that they can reach their full potential. The results of this study show clearly that moderate and intense exercise can have a significant impact on a range of performance tasks, fundamental to success in sport. The practical implications of these findings, therefore, are very significant and some of these are explored in more detail in the next section.

8.2 Practical implications

All players are aware of the feelings associated with muscle fatigue; the muscles feel tired, slow, weak and sometimes painful. Linked to this is the fact that players are constantly striving for improvement or to extend the limits of their performance. In many cases, this means delaying the moment when fatigue causes them to slow down (Jones, 1999). This programme of research set out to examine how fatigue impacts on sports performance and to explore whether fatigue effects on performance were the same regardless of the level of expertise. The percentage of time spent in possession of the ball is very small indeed in many of the sports focussed on in this work. In soccer, for example, only 2% of the total distance covered is in possession of the ball (Reilly, 1997) while in hurling the percentage of time in game-related play is just 3% (O’Donoghue et al., 2004). Therefore, there is often huge pressure on players to use the ball constructively, once possession is gained. Any factor or phenomenon that impacts on this has practical implications for players, coaches and trainers alike.

This programme of research has demonstrated clearly that the ability to perform sports skills is significantly compromised in both expert and non-expert players following high-intensity exercise. The rate of decline was explored specifically in the basketball study and the findings showed that the decline in performance from rest to high-intensity exercise is significantly greater in non-expert players. Therefore, if high-intensity exercise is detrimental to the performance of key sport skills it should be considered when planning training programmes, particularly with non-expert players since the rate of decline in their performance is greater. There may be an argument for coaches to consider integrating short bouts of high-intensity exercise into skill sessions. It would be important that the training simulates, as much as possible, the high-intensity exercise periods or bouts typical of a competitive game. If this type of exercise could be developed and integrated with drills and skills work it may enable players to maintain a higher standard of play or performance during competition.

Related to this, it is well known that the affective perception of pain is often different from the pure sensory (Fernandez & Turk, 1992). The sensory perceptions of pain refer to the actual intensity while the affective also includes the person's emotional response to the sensation. Individuals who are used to the feelings of distress induced by heavy exercise would presumably have a different affective perception than those not familiar with the sensation. Therefore, practicing skills under high-intensity exercise conditions may result in a lessening of the inhibitory effects of fatigue (McMorris et al., 1994). In this case, players may become accustomed to high-intensity exercise and the associated feelings of distress with this intensity level, and over time cope better with the ensuing demands. This may then prevent the detrimental effects of high-intensity exercise observed in a number of studies conducted here.

Previous studies examining such an approach are relatively scarce but Royal (2004) did hypothesise that training under exercise conditions or elevated fatigue may lead to a short-term deterioration in performance and that such an approach may result in an even stronger transfer of performance effect over time. Of the few available studies relating to this, Arnett, DeLuccia and Gilmartin (2000) found that practising a gross motor task, under conditions of anaerobic fatigue, facilitated transfer of performance of the same task under similar fatigue conditions in male participants only. Anshel and Novak (1989) however, found that training when highly fatigued led to a deterioration in overall performance. However, if training is conducted under conditions of high exertion or high-intensity exercise, an important consideration for the coach would be the need to monitor technique. If technique deteriorated, then such training would need reconsideration as it would prove counter-productive or worse still, lead to injury.

One finding of this research which has wide ranging practical implications was the deterioration in attention with high-intensity exercise. The way in which attention is directed, allocated and maintained is of primary interest to exercise physiologists, sport scientists, and coaches (Fernandez-Duque & Johnson, 1999). Many regard attention as limited in nature and subject to negative disruptions caused by both internal and external distractions (Moran, 1996). In sports that require attention and alertness to successfully execute multiple tasks, understanding how performers respond to attentional demands under stable and variable conditions is essential (Lal & Craig, 2002). The Stroop study showed very clearly that high-intensity exercise leads to a deterioration in attention. It is widely accepted that maintenance of appropriate attention is not only important for task performance (Nideffer, 1993), but also important in terms of athlete safety. This finding therefore, has many practical implications. If a player's attention deteriorates with high-intensity exercise, coaches need to consider training methods that may enable a player to cope with, or avoid, the development of fatigue so that optimal levels of attention are maintained. More research is needed however, pertaining to this as only one study in this program of research examined this fundamental aspect of sports performance.

Generally, across all of the studies conducted in this research, exercise at a moderate-intensity led to no change in performance. Numerous physiological and/or neurophysiological changes (Davranche & Audiffren, 2004) are predicted as a result of completing moderate-intensity exercise. Physiological changes may include increased blood flow or warming up of the musculature and neurophysiological changes may include increased speed of nerve transmission within the PNS. The findings here show that these performance enhancing benefits were not experienced and if they were they did not manifest in the performance of the players. In soccer, for example, this may have implications for the intensity of exercise when warming up, re-warming up prior to the second half or the warming up of substitutes before they commence play. Research of this nature is not new (Mohr et al., 2004) but the findings of this work may contribute to what is currently available. Oxendine (1984) has stated that different tasks may require different intensities of exercise before facilitation will be exhibited. The results of this research show that this may be the case.

Yet again, the findings of the hurling study have practical significance or application as they showed that, regardless of level of expertise, exercise intensity for the most part does not affect CAT ability. The findings support other work which concluded that fatigue has no effect on the afferent pathways involved in this type of information-processing activity (Bard & Fleury, 1978; Fleury, Bard & Carrière, 1981; Fleury et al., 1981; Al-Nakeeb et al., 2005; Al-Nakeeb & Lyons, 2007). Additionally, this study provided some evidence that players can recover rapidly from exercise (Figure 18), reinforcing even further the transient nature of this phenomenon.

To conclude, it is only through greater understanding of the construct of exercise and/or fatigue, that it becomes possible to reorganise training and practical regimens, as well as coaching philosophies. Coaches and athletes become more aware of how players are affected by the physical demands of their sport and other related phenonena. Understanding the effects of exercise / fatigue on performance can certainly improve related training practices and coping techniques. By manipulating or inducing physiological constraints (e.g. fatigue) during practice sessions, players may learn to become more attentive to the associated symptoms and be taught to successfully inhibit the development and/or influence of fatigue on performance (Gopher, 1992).

8.3 Limitations of the research

With any programme of research, there should be a clear rationale for the methods chosen and in the case of the present work, these methods and their justification have been outlined for each of the studies conducted. However, while the methodologies have a clear rationale and sound theoretical basis, it is also true that there are some limitations in the work. These have been acknowledged in published work outlined in the preface. The nature of this programme of work, with its emphasis on field-based research meant that the studies conducted would inevitably have some inherent restrictions. In both the soccer and basketball studies, for example, the tasks used to set the exercise intensities were not identical to that experienced in the game situation. In both soccer and basketball there are natural breaks in play that enable players to recover and so in the case of these studies explicitly, the intensity may have been greater than players would typically be accustomed to. However, it is also important to recognise the difficulties in trying to replicate the match demands of soccer, difficulties which have been recognised by a number of past authors. The tests used in this research aimed at developing moderate and intense exercise states based on individual fitness levels or capacities, in appropriate field settings, using protocols that impacted on the muscle groups used in the criterion task. The protocols served these aims well. It is also fundamental to highlight that, with respect to the basketball and hurling investigations, field-based protocols that replicates the exercise patterns observed during match play do not yet exist in the scientific literature.

In soccer, there has been increasing emphasis on developing sport-specific fatigue protocols that replicate competitive match demands (Nicholas, Nuttall & Williams, 2000; Rahnama et al., 2003; Thatcher & Batterham, 2004). Most of these protocols, however, are based on protocols of fluctuating speeds (e.g. Drust, Reilly & Cable, 2000) and so do not distinguish between participants at different fitness levels.

Essential actions such as jumping, dribbling and kicking are not included in any such protocols and so even more stringently-controlled protocols do not fully reflect the muscle fatigue accumulated in competition. In soccer, basketball and hurling, tackles made and received, involvements with the ball, passes, sustaining forceful contractions and defensive pressure all contribute to the demands experienced during the game. Furthermore, the protocols do not consider the additional stresses of competition including psychological stress and the physical stress of contact with other players, the ball and the playing surface. As a result, the protocols used in this study and past work are unable to fully replicate the demands of competitive match play and are unable to create the sensory states of competition. Unfortunately, this means that in spite of the effort to maximise ecological validity, there will always be some compromise. Conducting the testing in a gymnasium in itself is another compromise is terms of ecological validity and so this is the challenge that presents future researchers of this topic.

With respect to the hurling study specifically, it has to be acknowledged that, ideally, anticipation should be measured on the field of play in order to maximise ecological validity. However, authors such as Abernethy (1988) recognise that examining this aspect of performance presents a difficult problem to the sport scientist and consequently, most applied studies of anticipation have taken place in the laboratory. Moreover, it is accepted in this study that the use of a light stimulus represented the stimulus of a ball in a match situation. Similarly, Brady (1996) acknowledged that the motion of the Bassin anticipation timer may not tap into the anticipatory demands of open skills sports. It should also be considered that in the game of hurling, players are often required to perform coincidence-anticipation movements based on the movement of players and the game state at that instant. Examining this in an experimental set-up would be very challenging.

The final point with respect to the hurling study is that the stimulus on the Bassin anticipation timer assumes a linear pathway and, in this research, a constant velocity was used. However, in many sports situations, motion assumes a curvilinear pathway due to acceleration and deceleration. In this study, it was intended to examine CAT using different stimulus speeds, acceleration and deceleration. Undoubtedly, this would be a more ecologically sound design as ball speeds vary within the game. This was evaluated in a pilot study but the use of variable speeds required regular resetting of the Bassin system and subsequent time delays. Given that fatigue is a continuous rather than a failure-point phenomenon, these delays would have been problematic. Speed of recovery can be an issue if measurements are not taken immediately on cessation of exercise (Cairns et al., 2005) and if the duration of the performance task is too long. Recovery from ensuing fatigue happens very quickly, particularly in fit individuals, and as a result of these factors, it was intentionally decided not to reset the systems speed to avoid potential recovery effects.

Noakes (2008) highlighted the fact that the physiology of human performance should never be divorced from the psychological component. This research did examine the effect of fatigue on one psychological element, namely attention. From the outset however, this work did not set out to manipulate related psychological phenomena such as emotional state or motivational state which impact greatly on sports performance. The findings of the initial investigations must be interpreted with this in mind, therefore.

With all research of this nature there are also some assumptions that are inherent. Verbal encouragement was provided by the researcher during all conditions throughout the studies in order to motivate the participants to give their best effort during the sessions. It is assumed therefore, that the participants on each testing session across all five studies produced their best effort to achieve the maximal performance they were capable of at that time. Recommendations that may address some of the limitations identified here will be discussed in the next section.

8.4 Recommendations for future research

With a research topic such as exercise / fatigue effects on performance, it is often very difficult to summarise the state of knowledge, to identify what is well established, what is speculative and to surmise what directions future research will take. For some of the questions raised in this thesis there are, in some instances, no definitive answers. There are likely to be many contributing variables, the significance of which may be unknown. This serves to illustrate that there are many gaps in the current literature relating to this topic and so further related research is imperative.

The series of related investigations undertaken as part of this programme of research have provided additional data on how exercise / fatigue affects key aspects of sports performance. However, future ecologically sound research is needed, examining fatigue effects on all aspects of sports performance. A key challenge for the researcher however, is to develop sport-specific protocols that simulate match conditions as closely as possible. The use of multiple-sprint, intermittent and discontinuous protocols need to be considered therefore. It is equally important that future research work employs performance tests that also display high ecological validity.

Ecologically valid research relating to exercise / fatigue effects on sports performance in expert and non-expert groups is very scant indeed. Research examining the impact of exercise / fatigue on attention and concentration in sport is also limited. There is a clear need for future research relating to these aspects of the research therefore, and such research would be of immense value to players, coaches, trainers and sport scientists at every performance level.

With respect to the hurling study in particular, future research should consider using a longer runway length, variable speeds and accelerations. This would make the design more ecologically valid ince the ball travels at variable speeds, accelerations and from varying distances in the game. It would also be preferable in future studies if players were made to intercept an actual ball as is required in the game. Consideration of the points here will ensure that future studies mimic more closely the variable nature of match conditions. Consequently, the ensuing results will have more applicability and relevance.

As with most factors or phenomena that impact on performance in sport, fatigue does not occur in isolation. Psychological and personality variables need to be examined in detail in an effort to clarify or better understand whether these variables interact with performances in a fatigued state. Past studies examining fatigue effects on performance for example, have not controlled for motivation. Future research needs to consider this and include controls for this. In essence, a multidisciplinary approach to exploring this topic is needed. It is advocated, therefore, that future research incorporates physiological, psychological and biomechanical analyses simultaneously so as to allow for a more comprehensive analysis of performance and greater understanding of exercise / fatigue effects on sports performance. Only when investigators examine the effects of exercise / fatigue on sports performance using a multidisciplinary approach, will they be able to understand this complex multidimensional construct and the variables or factors underlying performance.

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10.0 APPENDICES

Appendix I

Copy of Ethics Certificate

Appendix II

Sample informed consent (soccer study)

Informed Consent

I hereby agree to co-operate and participate in a research project entitled "the effect of moderate and high-intensity exercise on soccer passing accuracy" to be conducted by Mark Lyons.

It is my understanding that:

- I will be required to exercise at moderate and high intensities for varying periods of time.
- I will be given adequate time to warm-up in advance of any testing.
- All experimental procedures will be explained to me prior to their administration.
- I may ask questions of the researcher and expect pertinent responses.
- I may refuse to participate or may discontinue participation at any time without prejudice, question or reprimand.
- Benefits and/or risks of the research to me or others will be explained.
- All individual results and information will remain confidential and only used for the purposes of this research.
- The research will be made available to me on request.

I have read the information sheet and completed the medical history questionnaire attached here:

______________________	____________
Signature of Participant	**Date**
______________________	____________
Signature of Witness	**Date**
______________________	____________
Signature of Investigator	**Date**

Investigators Address
These details have been removed for data protection reasons.

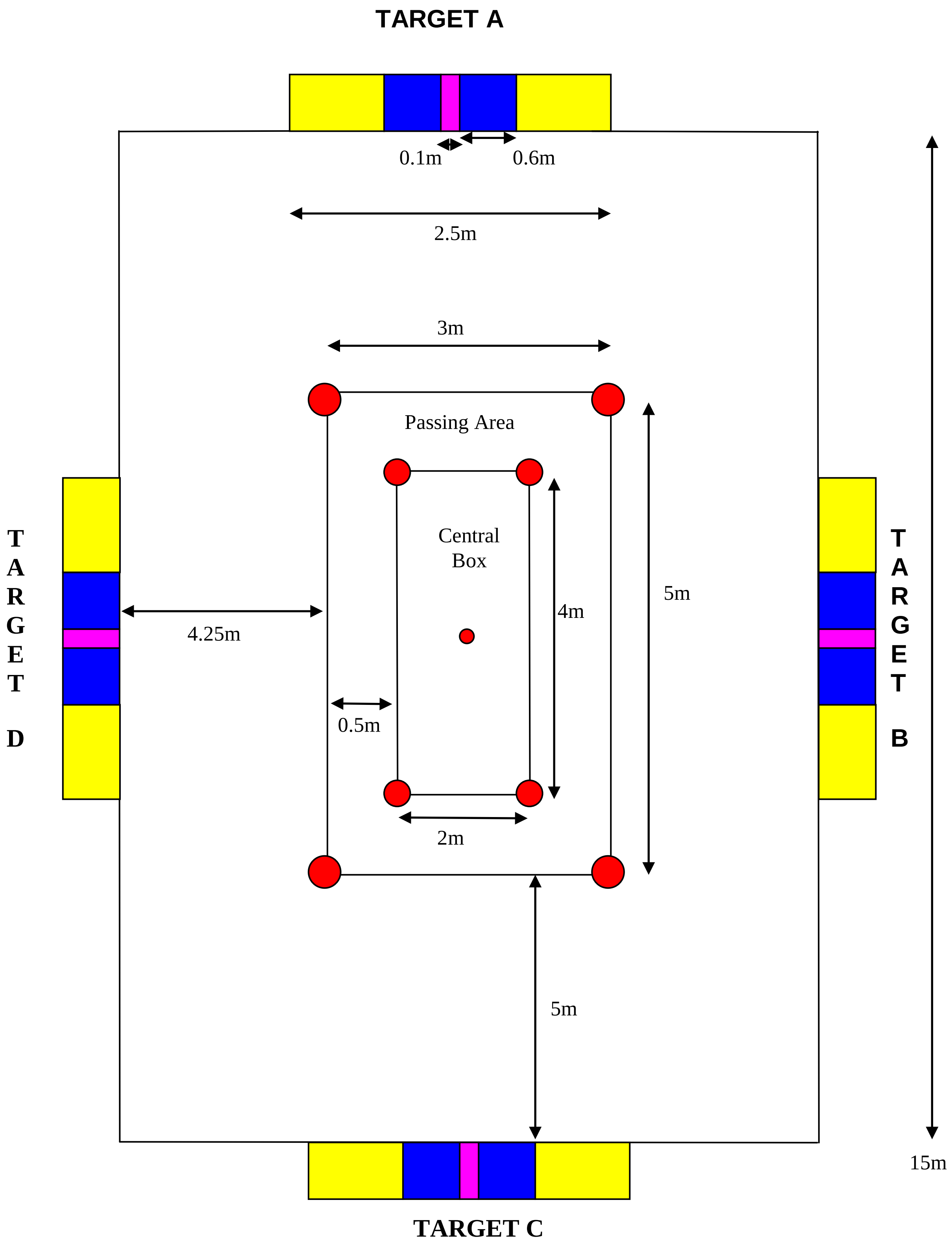
Investigators Telephone Number
These details have been removed
for data protection reasons

Appendix III

Sample medical history questionnaire

Appendix IV

Figure 5. Diagrammatic representation of the mLSPT



Appendix V

Table 3. Results of the repeated measures ANOVA conducted on the soccer passing data

	Type III sum of squares	**Df**	**Mean square**	**F**	**P**	**η^2**
Overall performance score	213.464	2	106.732	5.183	.010	.214
Passing penalties	52.300	2	26.150	6.980	.003	.269
Overall time penalties	213.525	2	106.762	9.384	< 0.001	.331

Appendix VI

Figure 12. Diagrammatic representation of the AAHPERD (1984)

Basketball Passing Test

Taken from: Strand and Wilson (1993)

Appendix VII

Table 4. Results of the 3 (exercise intensities) x 2 (levels of expertise) mixed ANOVA conducted on the basketball passing data

	Type III sum of squares	df	Mean square	F	P	η^2
3 x 2 ANOVA						
Exercise intensity	688.133	2	344.067	44.216	< 0.001	.711
Exercise intensity * expertise level	81.733	2	40.867	5.252	0.010	.226
Between-subject effects	30.817	1	30.817	.347	0.563	.019

Table 5. Results of the t-tests conducted on the rate of decline (Δ) in basketball passing performance in expert and non-expert players

	Levenes test for equality of variances					
	F	Sig.	T	df	P	η^2
	Equal variances assumed					
Decline (Rest to 70%)	.413	.528	2.861	18	0.01	.313
Decline (Rest to 90%)	.000	.985	3.215	18	.005	.365
Decline (70% to 90%)	.000	1.000	.775	18	.449	.032

Appendix VIII

Table 8. Results of the 3 (exercise intensities) x 2 (levels of expertise) mixed ANOVA conducted on the AE data

	Type III sum of squares	df	Mean square	F	P	η^2
3 x 2 ANOVA						
Exercise intensity	.001	2	.000	.246	.0783	.013
Exercise intensity * expertise level	.013	2	.007	3.839	.031	.176
Trials	.048	19	.003	2.473	.001	.121
Exercise intensity * trials	.053	38	.011	1.624	.011	.083
Between-subject effects	.046	1	.046	19.437	< 0.001	.519

Table 9. Results of the repeated measures ANOVA conducted on the expert and non-expert players' AE data

	Type III sum of squares	df	Mean square	F	P	η^2
Expert Players						
Exercise intensity	.004	2	.002	1.332	.286	.118
Non-expert Players						
Exercise intensity	.062	2	.002	1.609	.016	.0167

Table 10. Results of the 3 x 2 mixed ANOVA conducted on the logVE data

	Type III sum of squares	**df**	**Mean square**	**F**	**P**	**η^2**
3 x 2 ANOVA						
Exercise intensity	1.337	2	.668	.535	.590	.029
Exercise intensity * expertise level	8.149	2	4.074	3.259	.050	.153
Trials	37.453	19	1.971	2.006	.008	.100
Exercise intensity * trials	.065	38	.002	1.023	.434	.054
Between-subject effects	26.363	1	26.363	13.095	.002	.421

Table 11. Results of the repeated measures ANOVA conducted on the expert and non-expert players' logVE data

	Type III sum of squares	**df**	**Mean square**	**F**	**P**	**η^2**
Expert Players						
Exercise intensity	2.001	2	1.001	.613	.551	.058
Non-expert Players						
Exercise intensity	6.986	2	3.493	4.517	.028	361

Table 12. Results of the 3 x 2 mixed ANOVA conducted on the CE data

	Type III sum of squares	**df**	**Mean square**	**F**	**P**	**η^2**
3 x 2 ANOVA						
Exercise intensity	.000	2	.000	.041	.960	.002
Exercise intensity * expertise level	.003	2	.001	.538	.588	.029
Trials	.109	19	.006	1.865	.016	.094
Exercise intensity * trials	.093	38	.002	1.145	.256	.060
Between-subject effects	.008	1	.008	.417	.527	.023

Appendix IX

Sample parental consent form (tennis study)

Parental Consent

I hereby agree that ________________________ (name of child) can participate in a research study entitled "the effect of moderate and high-intensity exercise on groundstroke accuracy in tennis" to be conducted by Mark Lyons.

It is my understanding that the above named will be:

- Required to exercise at moderate and high intensities for varying periods of time.
- Given adequate time to warm-up in advance of any testing.
- Given clear explanations of all experimental procedures prior to their administration.
- Able to ask questions of the researcher and expect pertinent responses.
- Able to refuse to participate or may discontinue participation at any time without prejudice, question or reprimand.
- Made aware of both the benefits and/or risks of the research.
- Made aware of all the findings. Furthermore, all individual results and information will remain confidential and only used for the purposes of this research.

It is my understanding that I as the parent / guardian:

- May ask questions of the researcher and expect pertinent responses.
- May withdraw the above named at any time should I so wish without prejudice or question.

____________________________ ________________

Signature of Parent / Guardian **Date**

____________________________ ________________

Signature of Witness **Date**

____________________________ ________________

Signature of Investigator **Date**

Investigators Address
These details have been removed for data protection reasons.

Investigators Telephone Number
These details have been removed
for data protection reasons.

Appendix X

Sample 2 x 2 Achievement Goals Questionnaire for Sport

2 x 2 Achievement Goals Questionnaire for Sport

Please complete the following questionnaire before we start testing. It is important before completing this questionnaire that you consider your thoughts and feelings right now in terms of the activity you are just about to do. You need to respond to each of the 12 items on this sheet. You should respond using the following scale from 1 which indicates "this is not at all like me" to 7 which indicates "this is completely like me". Please respond to each of the 12 points as honestly as possible. Please circle as appropriate.

Scale

Mastery-approach

1. It is important to me to perform as well as I possibly can	1 2 3 4 5 6 7
2. I want to perform as well as it is possible for me to perform.	1 2 3 4 5 6 7
3. It is important for me to master all aspects of my performance.	1 2 3 4 5 6 7

Total scale score _____________

Mastery-avoidance

4. I worry that I may not perform as well as I possibly can.	1 2 3 4 5 6 7
5. Sometimes I am afraid that I may not perform as well as I would like.	1 2 3 4 5 6 7
6. I'm often concerned that I may not perform as well as I can perform.	1 2 3 4 5 6 7

Total scale score _____________

Performance-approach

7. It is important to me to do well compared to others.	1 2 3 4 5 6 7
8. It is important for me to perform better than others.	1 2 3 4 5 6 7
9. My goal is to do better than most other performers.	1 2 3 4 5 6 7

Total scale score _____________

Performance-avoidance

10. I just want to avoid performing worse than others.	1 2 3 4 5 6 7
11. My goal is to avoid performing worse than everyone else.	1 2 3 4 5 6 7
12. It is important for me to avoid being one of the worst performers in the group.	1 2 3 4 5 6 7

Total scale score _____________

Appendix XI

Figure 25. Diagrammatic representation of the modified Loughborough Tennis Skills Test: Groundstrokes (test 1)

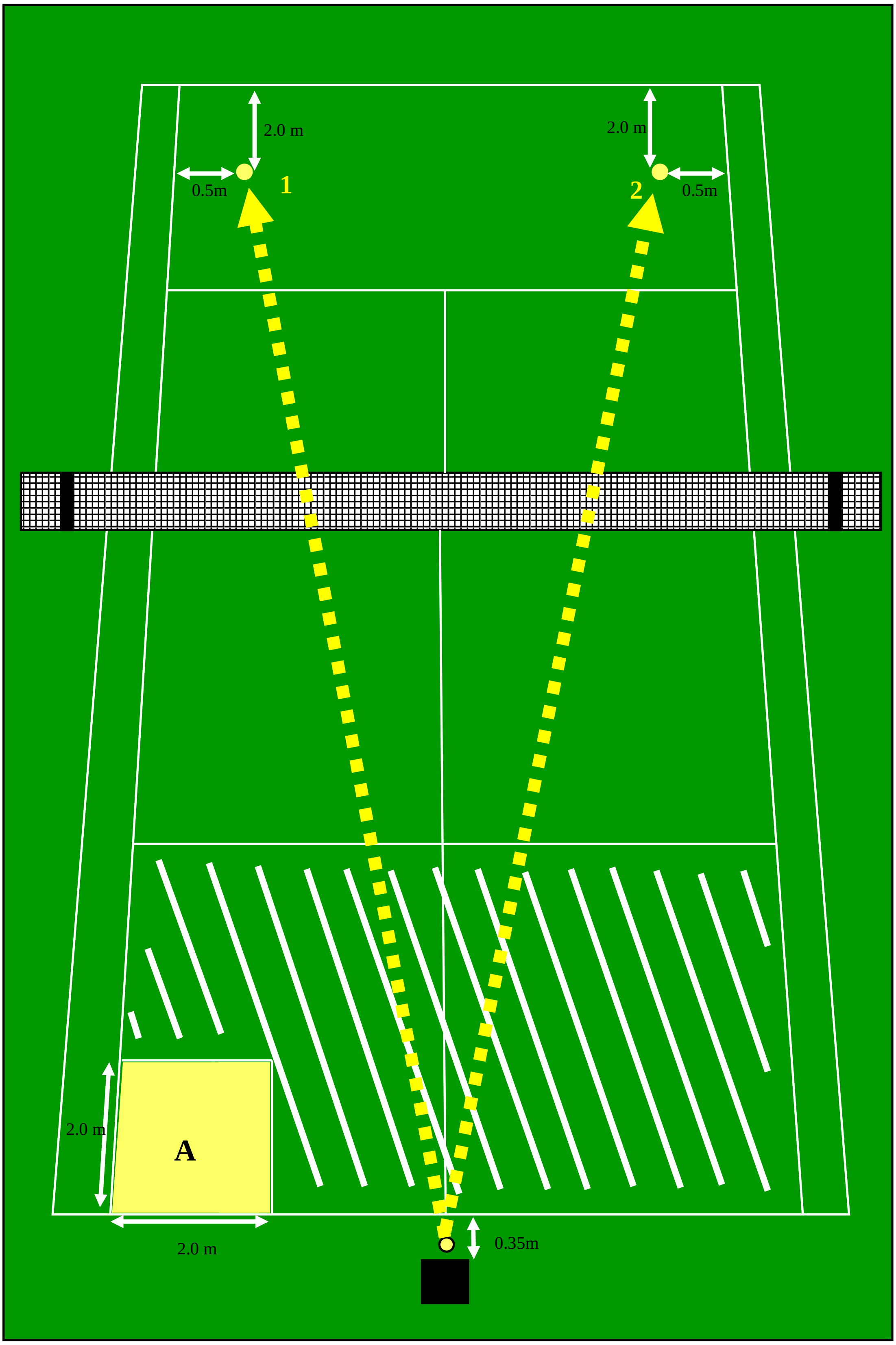
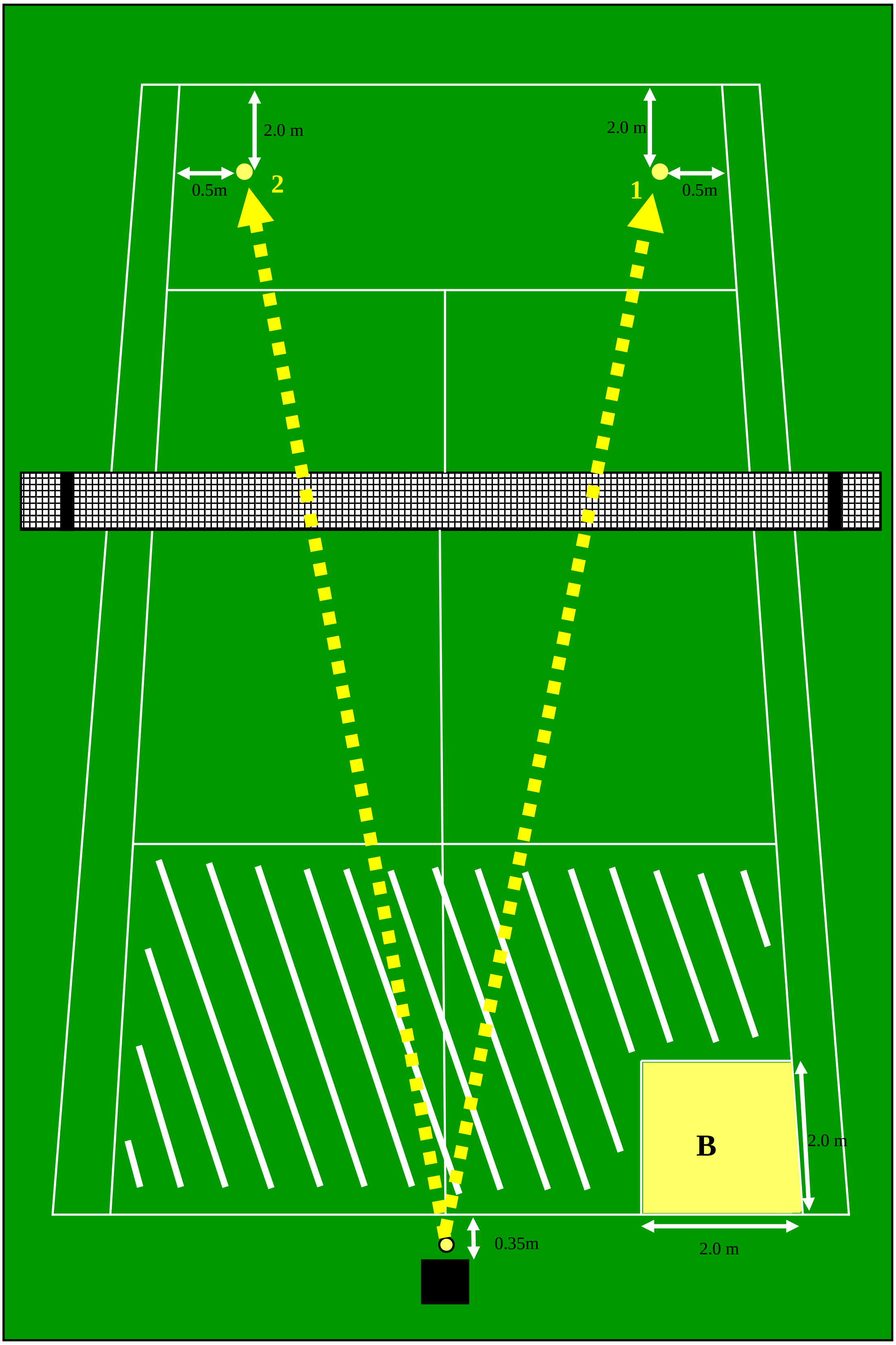
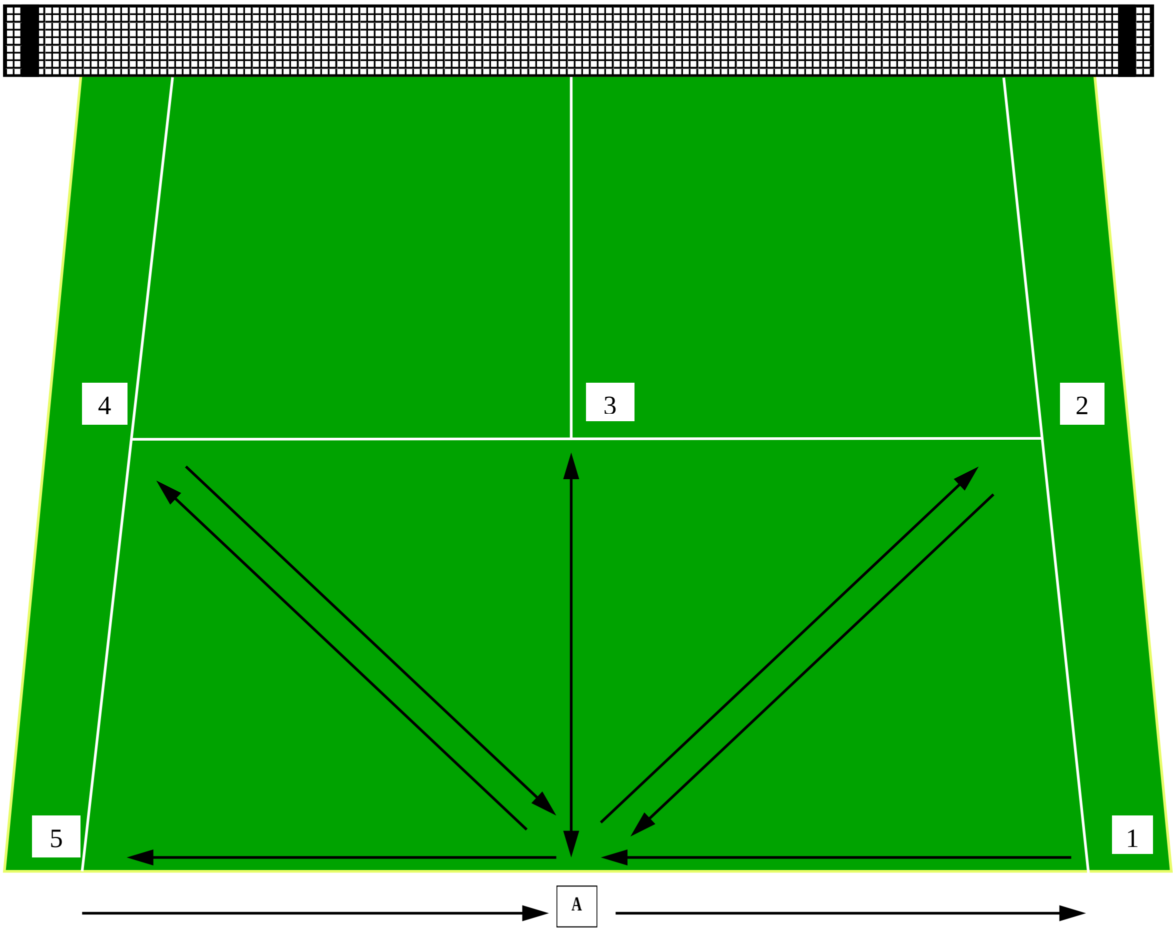


Figure 26. Diagrammatic representation of the modified Loughborough Tennis Skills Test: Groundstrokes (test 2)



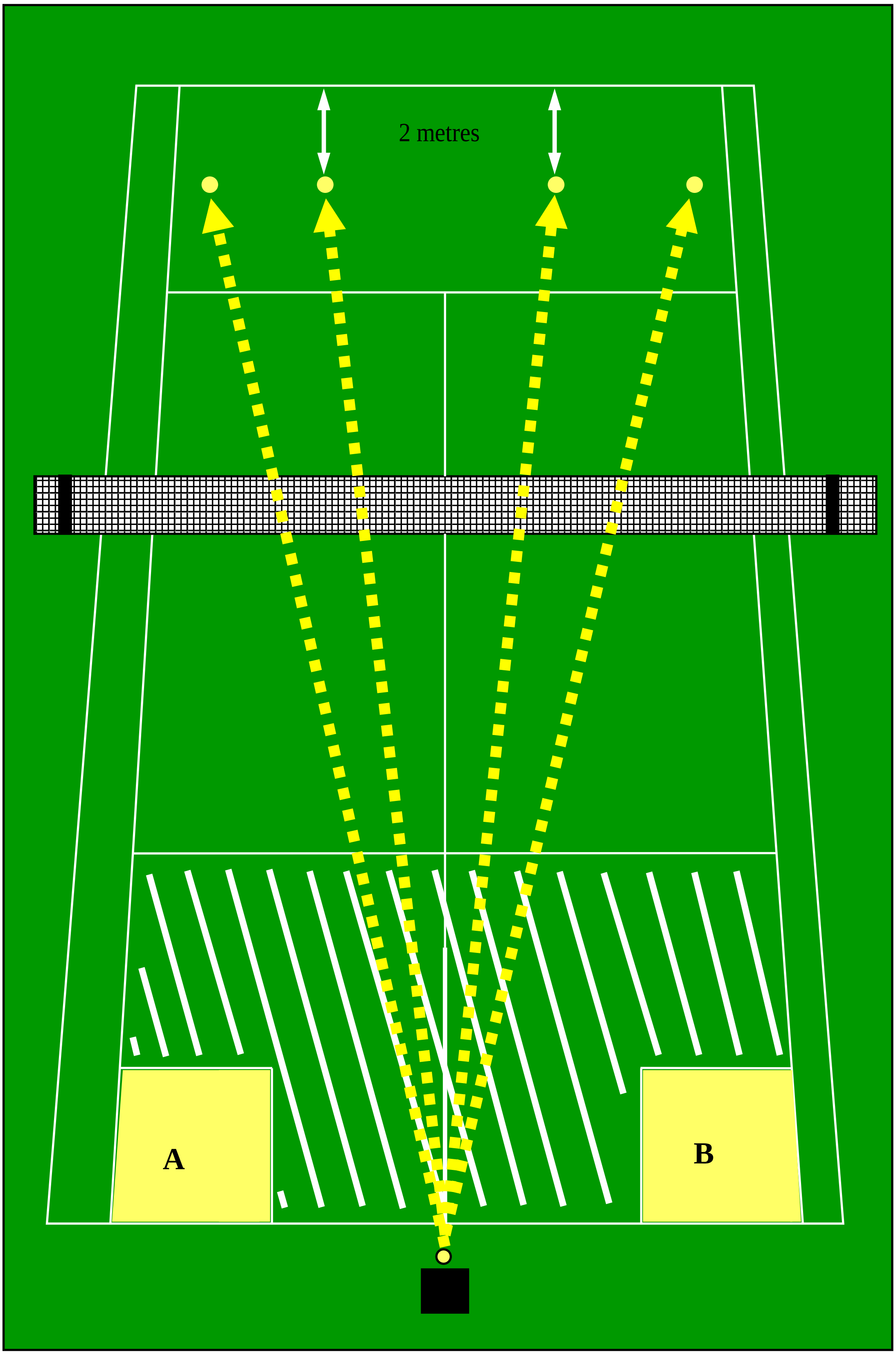
Appendix XII

Figure 29. Diagrammatic representation of the maximal Tennis Hitting Sprint Test



Appendix XIII

Figure 31. Diagrammatic representation of the Loughborough Intermittent Tennis Test



Appendix XIV

Mean (± SD) percentage data for tennis study

Table 15. ‘In’ percentages of the expert and non-expert tennis players for each shot across all exercise intensities

	Accuracy (%) Expert Players			Accuracy (%) Non-expert Players		
	Rest	**70%**	**90%**	**Rest**	**70%**	**90%**
DTLB	21.54 ± 15.73	16.15 ± 13.87	18.46 ± 17.25	16.47 ± 13.67	15.29 ± 12.31	10.59 ± 12.98
DTLF	33.08 ± 13.17	31.54 ± 16.76	10.00 ± 10.00	22.94 ± 22.30	12.94 ± 9.85	8.24 ± 8.83
CCB	16.92 ± 23.23	30.00 ± 12.25	15.38 ± 12.66	12.94 ± 9.20	19.41 ± 17.49	7.06 ± 12.13
CCF	27.69 ± 13.01	22.31 ± 14.23	15.38 ± 15.61	14.12 ± 15.84	17.06 ± 13.12	7.65 ± 7.52

Table 16. ‘Consistency’ percentages of the expert and non-expert tennis players for each shot across all exercise intensities

	Consistency (%) Expert Players			Consistency (%) Non-expert Players		
	Rest	**70%**	**90%**	**Rest**	**70%**	**90%**
DTLB	54.62 ± 20.26	50.00 ± 11.55	43.85 ± 11.21	34.12 ± 16.61	42.35 ± 14.37	33.53 ± 16.93
DTLF	49.23 ± 18.91	50.00 ± 19.58	53.85 ± 10.44	42.35 ± 20.78	45.29 ± 19.08	34.12 ± 13.72
CCB	56.92 ± 23.59	50.77 ± 13.21	47.69 ± 20.88	42.94 ± 15.72	49.41 ± 17.84	32.35 ± 19.85
CCF	50.00 ± 10.80	53.85 ± 19.38	54.62 ± 18.98	48.82 ± 21.76	49.41 ± 15.60	41.76 ± 17.04

Table 17. 'Out' percentages of the expert and non-expert tennis players for each shot across all exercise intensities

	Out (%) Expert Players			Out (%) Non-expert Players		
	Rest	**70%**	**90%**	**Rest**	**70%**	**90%**
DTLB	23.85 ± 12.61	33.85 ± 15.57	37.69 ± 14.23	49.41 ± 20.15	42.35 ± 19.54	55.88 ± 21.52
DTLF	17.69 ± 12.35	18.46 ± 16.76	36.15 ± 12.61	34.71 ± 20.04	41.76 ± 21.57	57.65 ± 13.93
CCB	26.15 ± 15.57	19.23 ± 10.38	36.92 ± 17.02	44.12 ± 15.84	31.18 ± 20.88	60.59 ± 22.21
CCF	22.31 ± 13.01	23.85 ± 13.87	30.00 ± 21.21	37.06 ± 23.12	33.53 ± 18.69	50.59 ± 19.83

Table 18. Percentages for both forehand shots combined, backhand shots combined and all shots combined in expert and non-expert tennis players

	Accuracy (%) Expert Players			Accuracy (%) Non-expert Players		
	Rest	**70%**	**90%**	**Rest**	**70%**	**90%**
Forehand Shots	30.38 ± 11.98	26.92 ± 12.34	12.69 ± 9.49	18.53 ± 17.92	15.00 ± 9.52	7.94 ± 6.14
Backhand Shots	19.23 ± 12.89	23.08 ± 9.69	16.92 ± 11.64	14.71 ± 9.10	17.35 ± 12.64	8.82 ± 10.08
All shots combined	24.81 ± 10.08	25.00 ± 8.96	14.81 ± 8.51	16.62 ± 10.00	16.18 ± 8.98	8.38 ± 7.23
	Consistency (%) Expert Players			**Consistency (%) Non-expert Players**		
	Rest	**70%**	**90%**	**Rest**	**70%**	**90%**
Forehand Shots	49.62 ± 11.27	51.92 ± 15.48	54.23 ± 12.22	45.59 ± 16.00	47.35 ± 12.39	37.94 ± 9.85
Backhand Shots	55.77 ± 16.94	50.38 ± 9.89	45.77 ± 13.97	38.53 ± 14.77	45.88 ± 12.53	32.94 ± 13.00
All shots combined	52.69 ± 12.50	51.15 ± 5.55	50.00 ± 10.00	42.06 ± 11.57	46.62 ± 7.65	35.44 ± 6.97
	Out (%) Expert Players			**Out (%) Non-expert Players**		
	Rest	**70%**	**90%**	**Rest**	**70%**	**90%**
Forehand Shots	20.00 ± 9.13	21.15 ± 13.10	33.08 ± 12.84	36.18 ± 18.84	37.65 ± 16.87	54.12 ± 12.15
Backhand Shots	25.00 ± 13.54	26.54 ± 10.68	37.31 ± 12.18	46.76 ± 16.10	36.76 ± 17.67	58.24 ± 17.76
All shots combined	22.50 ± 9.57	23.85 ± 8.70	35.19 ± 9.76	41.47 ± 13.75	37.21 ± 12.08	56.18 ± 9.89

Appendix XV

Figure 33. Percentage of 'in' shots across exercise intensities in expert and non-expert tennis players (forehand groundstrokes combined)

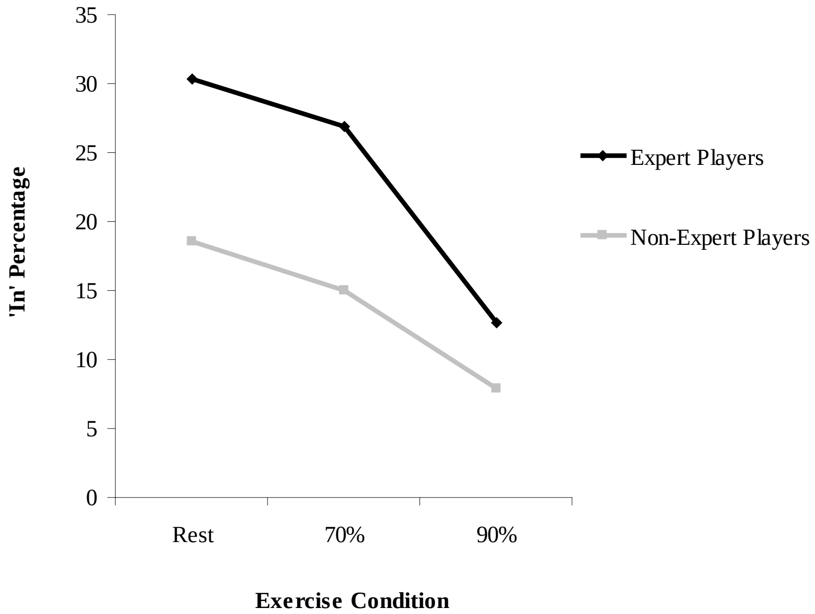
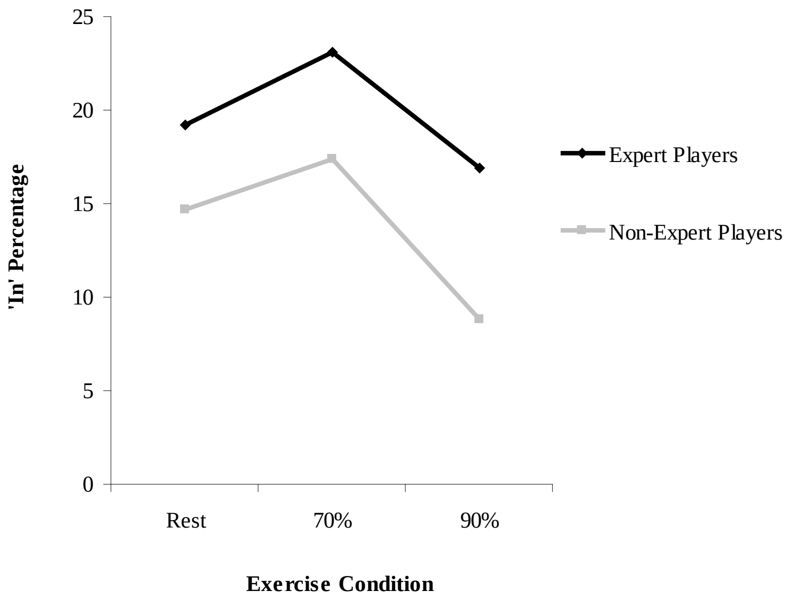


Figure 34. Percentage of 'in' shots across exercise intensities in expert and non-expert tennis players (backhand groundstrokes combined)



Appendix XVI

Figure 36. Percentage of 'out' shots across exercise intensities in expert and non-expert tennis players (forehand groundstrokes combined)

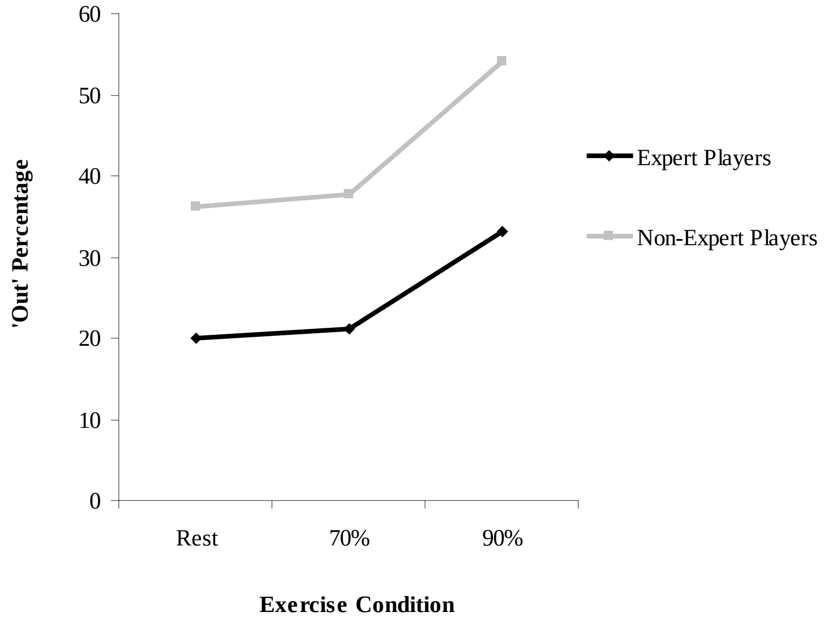
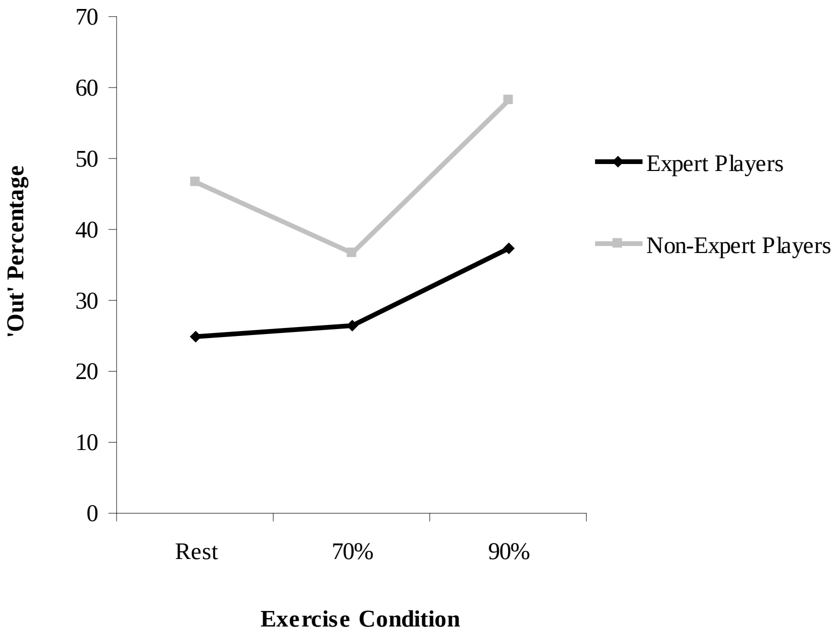


Figure 37. Percentage of 'out' shots across exercise intensities in expert and non-expert tennis players (backhand groundstrokes combined)



Appendix XVII

Table 19. Results of the 3 (exercise intensities) x 2 (levels of expertise) mixed ANOVA conducted on the ‘in’, ‘out’ and ‘consistency’ percentage data (all groundstroke shots combined)

	Type III sum of squares	df	Mean square	F	P	η^2
‘In’ Percentage						
Exercise intensity	1611.088	2	805.544	14.517	< 0.001	.341
Exercise intensity * level of expertise	22.755	2	11.378	.205	0.815	.007
Between-subject effects	1349.040	1	1349.04	10.302	.003	.269
‘Consistency’ Percentage						
Exercise intensity	608.572	2	304.286	5.093	0.009	.154
Exercise intensity * level of expertise	375.794	2	187.897	3.145	0.051	.101
Between-subject effects	2170.181	1	2170.181	15.391	0.001	.355
‘Out’ Percentage						
Exercise intensity	4121.119	2	2060.599	27.301	< 0.001	.494
Exercise intensity * level of expertise	230.008	2	115.004	1.524	0.227	.052
Between-subject effects	6979.754	1	6979.754	33.407	< 0.001	.544

Appendix XVIII

Table 20. Results of the 3 (exercise intensities) x 2 (males and females) mixed ANOVA conducted on the 'in', 'out' and 'consistency' percentage data (all groundstroke shots combined)

	Type III sum of squares	df	Mean square	F	P	η^2
'In' Percentage						
Exercise intensity	1355.625	2	677.813	12.404	< 0.001	.307
Exercise intensity * gender	70.069	2	35.035	.641	.531	.022
Between-subject effects	64.201	1	64.201	.363	.552	.013
'Consistency' Percentage						
Exercise intensity	479.236	2	239.618	4.051	.023	.126
Exercise intensity * gender	408.958	2	204.479	3.457	.038	.110
Between-subject effects	690.312	1	690.312	3.561	.070	.113
'Out' Percentage						
Exercise intensity	3418.819	2	1709.410	22.636	< 0.001	.447
Exercise intensity * gender	227.708	2	113.854	1.508	.230	.051
Between-subject effects	320.000	1	320.000	.716	.405	.025

Appendix XIX

Figure 42. Percentage of 'consistent' shots across exercise intensities in male and female tennis players (all groundstrokes combined)

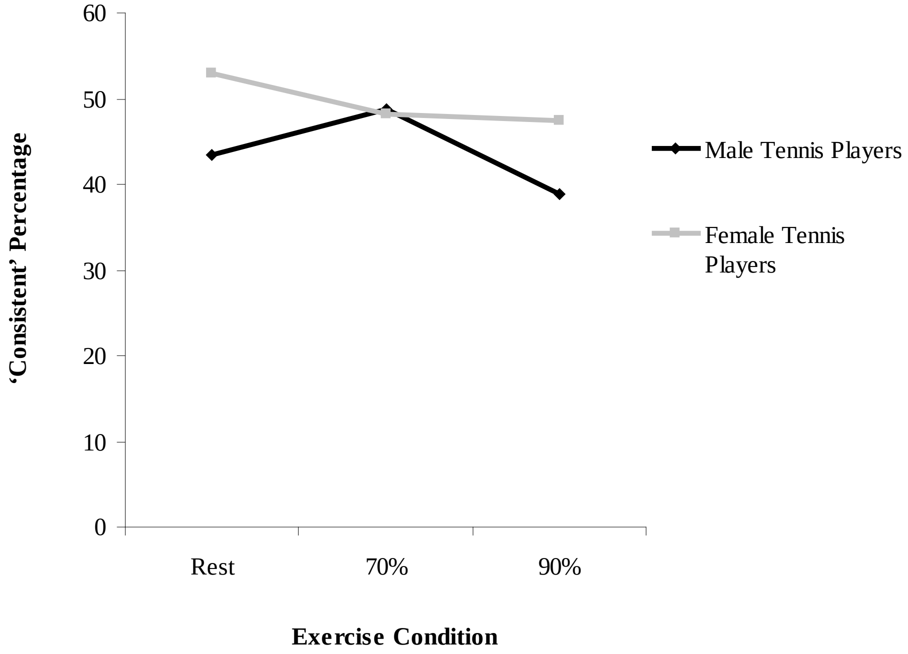
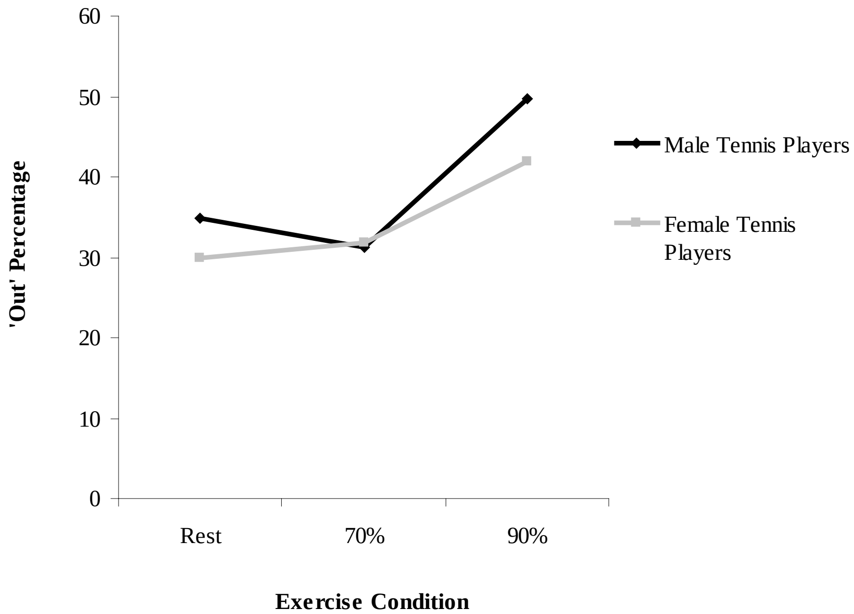


Figure 43. Percentage of 'out' shots across exercise intensities in male and female tennis players (all groundstrokes combined)



Appendix XX

Table 21. Results of the 3 (exercise intensities) x 2 (high and low approach) mixed ANOVA conducted on the 'in', 'out' and 'consistency' percentage data (all groundstroke shots combined)

	Type III sum of squares	df	Mean square	F	P	η^2
'In' Percentage						
Exercise intensity	1590.556	2	795.278	14.513	< 0.001	.341
Exercise intensity * approach	61.667	2	30.838	.563	.573	.020
Between-subject effects	2.500	2	2.500	.014	.907	.000
'Consistency' Percentage						
Exercise intensity	745.417	2	372.708	5.889	.005	.174
Exercise intensity * approach	182.917	2	91.458	1.447	.244	.049
Between-subject effects	422.500	1	422.500	2.077	.161	.069
'Out' Percentage						
Exercise intensity	4401.667	2	2200.883	29.152	< 0.001	.510
Exercise intensity * approach	228.889	2	114.444	1.516	.228	.051
Between-subject effects	370.069	1	370.069	.832	.370	.029

Appendix XXI

Table 22. Results of the 3 (exercise intensities) x 2 (high and low avoidance) mixed ANOVA conducted on the ‘in’, ‘out’ and ‘consistency’ percentage data (all groundstroke shots combined)

	Type III sum of squares	df	Mean square	F	P	η^2
‘In’ Percentage						
Exercise intensity	1637.830	2	818.915	15.156	< 0.001	.351
Exercise intensity * approach	104.497	2	52.248	.967	.386	.033
Between-subject effects	277.442	1	277.442	1.640	.211	.055
‘Consistency’ Percentage						
Exercise intensity	745.308	2	372.654	5.634	.006	.168
Exercise intensity * approach	17.530	2	8.765	.133	.876	.005
Between-subject effects	61.116	1	61.116	.283	.599	.010
‘Out’ Percentage						
Exercise intensity	4485.357	2	2242.679	29.357	< 0.001	.512
Exercise intensity * approach	178.690	2	89.345	1.170	.318	.040
Between-subject effects	611.116	1	611.116	1.400	.247	.048

Appendix XXII

Raw data

Soccer Study – Raw Data

Age	Height	Weight	Max No. Squats	No. Squats (70%)	No. Squats (90%)	CE Rest	CE 70%	CE 90%	PE Rest	PE 70%	PE 90%	P&CE Rest	P&CE 70%	P&CE 90%	Total E Rest	Total E 70%	Total E 90%	PS Rest	PS 70%	PS 90%
23	174	73	105	74	95	1	2	2	5.5	5	9	5.5	7	11	8	12	12	34.11	40.88	36.97
31	171	69	138	97	125	1	2	2	6	8	7	6	10	9	16	17	17	49.28	47.66	48.19
21	183	77	126	88	113	3	0	4	6.5	5	11	9.5	5	15	13.5	8	15	40.56	35.53	37.95
23	176	105	97	68	87	0	0	2	12	12	13	12	12	16	15.5	16	19	42.86	42.87	46.03
42	177	79	127	89	114	1	0	8	7.5	9	10	8.5	9	18	8.5	9	18	30.40	32.09	39.59
18	183	67	145	102	130	0	0	0	7	5	7	7	5	7	18.5	11	15	53.64	40.34	46.88
23	177	70	115	80	104	0	2	0	6.5	0	5	6.5	2	5	6.5	2	5	28.49	25.25	26.19
26	168	65	127	89	114	1	0	10	10	8	12	11	8	22	12.5	9	22	37.50	33.47	45.90
21	155	53	110	77	99	4	2	0	10.5	13	14	14.5	15	14	32.5	36	30	74.12	80.38	69.40
20	186	80	105	67	95	0	2	8	11.5	12	14	11	14	22	20.5	23	33	52.48	55.60	67.87
20	187	91	110	77	99	2	0	8	4.5	9	12	6.5	9	20	13.5	17	27	44.09	48.25	57.94
24	183	102	120	84	108	0	0	0	8.5	13	12	8.5	13	12	11	19	17	36.95	48.50	45.30
21	183	70	127	89	114	1	0	2	11	7	11	12	7	13	17	13	16	45.55	42.88	42.26
23	185	70	142	100	128	1	2	0	5	8	7	6	10	7	7	10	7	31.42	32.13	29.56
22	175	67	130	91	117	0	0	0	7.5	9	13	7.5	9	13	11.5	12	17	39.29	38.94	44.17
19	172	75	127	89	114	0	0	0	7.5	4	9	7.5	4	9	7.5	4	13	30.92	27.12	40.22
22	175	71	100	70	90	2	0	4	10.5	6	8	11.5	6	13	11.5	6	13	35.11	28.46	37.66
21	181	87	131	92	118	2	2	2	9	8	5	11	10	7	11	10	10	35.17	32.64	36.25
20	181	78	110	77	99	0	2	2	9	6	11	9	8	13	9	8	16	32.07	29.08	42.82
19	187	91	140	98	126	5	2	2	8.5	9	9	13.5	11	14	18.5	11	18	47.44	34.80	45.15

Basketball Study – Raw Data

Expertise	Age	Height	Weight	Perf Rest	Perf 70	Perf 90	No. P Rest	No. P 70	No. P 90	Rate D 70	Rest D 90
1	24	176	75	49	48	35	25	24	19	-1	-14
1	23	187	106	40	42	38	20	21	19	2	-2
1	23	185	87	46	50	44	23	25	22	4	-2
1	24	177	85	55	52	46	28	26	23	-3	-9
1	23	183	93	51	51	48	26	26	26	0	-3
1	21	172	87	44	38	43	22	19	23	-6	-1
1	20	187	78	48	46	42	24	24	22	-2	-6
1	22	192	107	40	44	34	20	22	17	4	-6
1	23	180	67	58	56	54	29	28	27	-2	-4
1	22	186	93	58	56	52	29	28	26	-2	-6
2	22	175	69	56	52	40	28	26	22	-4	-16
2	21	158	52	40	36	31	20	19	16	-4	-9
2	21	187	84	49	44	38	25	22	21	-5	-11
2	26	168	65	59	58	42	31	29	22	-1	-17
2	24	182	102	50	48	40	26	24	20	-2	-10
2	23	186	93	52	48	48	26	24	24	-4	-4
2	24	181	99	56	46	42	28	23	22	-10	-14
2	19	183	70	46	44	36	24	22	21	-2	-10
2	31	171	69	50	42	40	25	21	20	-8	-10
2	23	175	102	48	44	40	24	22	20	-4	-8

Hurling Study – Absolute Error Raw Data

Expertise	Height	Weight	RHR	HRR70	HRR90	RPE70	RPE90	TTF70	TTF90	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14
1	184	104	53	153	182	15	18	330	390	0.005	0.023	0.007	0.046	0.004	0.032	0.020	0.021	0.012	0.006	0.056	0.022	0.007	0.023
2	179	85	64	156	182	15	19	340	410	0.051	0.006	0.020	0.054	0.156	0.039	0.062	0.022	0.103	0.054	0.026	0.054	0.031	0.027
2	181	99	65	130	183	16	19	270	330	0.030	0.063	0.032	0.041	0.049	0.075	0.050	0.084	0.151	0.046	0.013	0.019	0.016	0.009
2	185	93	55	155	183	15	19	330	450	0.095	0.053	0.042	0.079	0.001	0.023	0.073	0.019	0.080	0.038	0.004	0.064	0.074	0.032
1	182	67	55	155	184	15	19	440	495	0.075	0.063	0.013	0.097	0.026	0.042	0.013	0.041	0.014	0.054	0.006	0.059	0.022	0.050
1	182	68	68	161	188	16	20	440	530	0.058	0.043	0.003	0.019	0.094	0.011	0.055	0.002	0.027	0.069	0.063	0.017	0.004	0.050
1	185	84	67	159	185	17	20	370	450	0.036	0.026	0.007	0.046	0.021	0.051	0.002	0.036	0.020	0.024	0.044	0.060	0.091	0.040
1	179	97	60	147	172	16	19	360	370	0.054	0.078	0.018	0.067	0.072	0.040	0.034	0.003	0.048	0.080	0.002	0.010	0.044	0.037
2	171	80	75	142	162	15	18	300	390	0.002	0.040	0.046	0.050	0.003	0.063	0.017	0.026	0.084	0.079	0.028	0.148	0.093	0.066
2	175	105	70	160	185	15	20	300	465	0.044	0.013	0.053	0.059	0.091	0.137	0.036	0.040	0.063	0.087	0.03	0.028	0.015	0.044
2	187	87	52	153	183	17	19	360	450	0.029	0.117	0.023	0.009	0.042	0.094	0.078	0.050	0.030	0.017	0.034	0.066	0.029	0.009
1	190	87	55	155	184	17	19	315	420	0.023	0.017	0.009	0.058	0.102	0.014	0.019	0.001	0.063	0.004	0.026	0.045	0.048	0.001
1	177	71	60	156	183	17	19	380	480	0.108	0.001	0.067	0.010	0.007	0.052	0.021	0.023	0.061	0.010	0.014	0.033	0.002	0.021
1	174	73	60	157	185	15	19	323	500	0.022	0.055	0.049	0.002	0.019	0.014	0.003	0.016	0.025	0.051	0.063	0.010	0.003	0.006
1	173	68	69	159	185	15	19	360	450	0.101	0.115	0.031	0.017	0.027	0.002	0.081	0.078	0.092	0.041	0.006	0.029	0.020	0.029
1	187	80	70	156	184	17	19	265	430	0.023	0.003	0.008	0.003	0.078	0.043	0.018	0.027	0.035	0.010	0.016	0.001	0.021	0.005
1	187	87	60	156	184	15	19	330	420	0.035	0.073	0.009	0.037	0.118	0.026	0.077	0.019	0.068	0.051	0.041	0.019	0.013	0.059
2	175	84	60	156	184	17	19	270	390	0.022	0.054	0.043	0.027	0.065	0.051	0.084	0.032	0.056	0.019	0.050	0.009	0.033	0.046
2	176	86	54	152	181	17	19	300	405	0.076	0.082	0.014	0.042	0.036	0.101	0.032	0.046	0.081	0.032	0.014	0.009	0.019	0.091
2	179	88	50	173	183	17	19	280	420	0.117	0.084	0.062	0.091	0.080	0.110	0.034	0.046	0.090	0.076	0.081	0.052	0.041	0.022

R15	R16	R17	R18	R19	R20	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17
0.012	0.061	0.003	0.010	0.001	0.012	0.073	0.021	0.081	0.030	0.058	0.042	0.057	0.033	0.097	0.044	0.051	0.084	0.068	0.014	0.053	0.011	0.066
0.052	0.013	0.020	0.051	0.027	0.065	0.057	0.066	0.039	0.067	0.029	0.027	0.058	0.031	0.005	0.079	0.015	0.075	0.063	0.039	0.074	0.032	0.005
0.116	0.032	0.056	0.047	0.042	0.019	0.046	0.004	0.094	0.117	0.080	0.052	0.043	0.012	0.002	0.030	0.047	0.044	0.064	0.043	0.069	0.035	0.038
0.093	0.033	0.046	0.045	0.035	0.048	0.093	0.024	0.003	0.011	0.030	0.001	0.019	0.049	0.001	0.095	0.081	0.040	0.041	0.011	0.036	0.014	0.019
0.010	0.039	0.072	0.024	0.005	0.008	0.005	0.014	0.012	0.026	0.037	0.013	0.023	0.123	0.009	0.054	0.089	0.024	0.013	0.045	0.071	0.123	0.018
0.059	0.041	0.072	0.008	0.034	0.036	0.025	0.009	0.002	0.011	0.030	0.055	0.015	0.008	0.012	0.060	0.030	0.058	0.001	0.010	0.051	0.003	0.035
0.027	0.006	0.023	0.026	0.041	0.089	0.010	0.011	0.027	0.059	0.013	0.046	0.068	0.062	0.004	0.026	0.048	0.049	0.039	0.021	0.020	0.027	0.046
0.018	0.011	0.016	0.025	0.024	0.042	0.131	0.100	0.088	0.078	0.041	0.002	0.062	0.011	0.019	0.067	0.029	0.055	0.009	0.080	0.017	0.003	0.079
0.036	0.113	0.072	0.145	0.101	0.044	0.071	0.055	0.023	0.048	0.027	0.024	0.014	0.019	0.022	0.039	0.009	0.051	0.022	0.053	0.006	0.046	0.058
0.113	0.157	0.025	0.135	0.072	0.028	0.015	0.02	0.036	0.004	0.011	0.038	0.125	0.102	0.022	0.006	0.083	0.007	0.028	0.081	0.095	0.050	0.028
0.038	0.037	0.065	0.025	0.074	0.022	0.047	0.078	0.006	0.003	0.098	0.002	0.054	0.084	0.077	0.001	0.003	0.072	0.010	0.066	0.021	0.068	0.022
0.012	0.044	0.076	0.014	0.022	0.057	0.027	0.014	0.013	0.029	0.006	0.036	0.037	0.032	0.036	0.037	0.001	0.058	0.029	0.055	0.076	0.022	0.007
0.041	0.041	0.051	0.043	0.028	0.040	0.122	0.013	0.038	0.009	0.019	0.006	0.010	0.023	0.073	0.044	0.021	0.003	0.016	0.003	0.034	0.014	0.050
0.022	0.019	0.068	0.027	0.009	0.015	0.037	0.018	0.066	0.037	0.079	0.056	0.002	0.006	0.034	0.062	0.048	0.003	0.016	0.090	0.033	0.038	0.022
0.018	0.065	0.040	0.004	0.003	0.009	0.060	0.071	0.018	0.002	0.042	0.094	0.031	0.026	0.041	0.032	0.016	0.027	0.019	0.040	0.006	0.013	0.005
0.013	0.024	0.005	0.041	0.045	0.068	0.036	0.023	0.056	0.091	0.087	0.042	0.048	0.001	0.134	0.039	0.057	0.030	0.069	0.012	0.100	0.116	0.018
0.079	0.052	0.026	0.025	0.054	0.033	0.081	0.018	0.048	0.070	0.027	0.075	0.088	0.035	0.005	0.058	0.043	0.059	0.014	0.037	0.033	0.004	0.080
0.045	0.035	0.048	0.079	0.003	0.038	0.081	0.040	0.036	0.014	0.019	0.040	0.066	0.024	0.117	0.080	0.030	0.064	0.043	0.069	0.035	0.038	0.046
0.067	0.092	0.112	0.052	0.074	0.081	0.038	0.006	0.083	0.007	0.081	0.095	0.032	0.011	0.073	0.022	0.111	0.055	0.058	0.084	0.036	0.107	0.072
0.009	0.008	0.042	0.031	0.019	0.068	0.084	0.019	0.080	0.091	0.081	0.054	0.049	0.032	0.086	0.069	0.029	0.037	0.061	0.054	0.008	0.017	0.028

M18	M19	M20	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20
0.013	0.045	0.014	0.025	0.002	0.006	0.007	0.001	0.023	0.001	0.020	0.011	0.027	0.032	0.072	0.028	0.008	0.064	0.021	0.015	0.008	0.001	0.025
0.015	0.009	0.004	0.077	0.064	0.022	0.023	0.014	0.016	0.032	0.024	0.004	0.065	0.034	0.129	0.041	0.038	0.070	0.071	0.066	0.022	0.064	0.001
0.046	0.043	0.006	0.093	0.012	0.051	0.024	0.045	0.023	0.031	0.031	0.038	0.023	0.031	0.103	0.044	0.004	0.012	0.058	0.008	0.028	0.031	0.034
0.009	0.040	0.066	0.176	0.048	0.022	0.022	0.106	0.018	0.004	0.012	0.138	0.017	0.156	0.001	0.050	0.024	0.053	0.037	0.035	0.004	0.039	0.006
0.054	0.024	0.061	0.003	0.068	0.003	0.049	0.036	0.049	0.022	0.042	0.028	0.008	0.046	0.054	0.017	0.053	0.021	0.085	0.005	0.045	0.015	0.064
0.025	0.005	0.039	0.063	0.073	0.037	0.054	0.035	0.007	0.013	0.028	0.069	0.013	0.040	0.010	0.006	0.004	0.007	0.033	0.055	0.013	0.011	0.025
0.093	0.008	0.012	0.102	0.069	0.010	0.026	0.002	0.005	0.049	0.039	0.059	0.056	0.064	0.047	0.022	0.040	0.044	0.057	0.002	0.035	0.006	0.005
0.050	0.045	0.105	0.059	0.060	0.051	0.027	0.133	0.003	0.008	0.014	0.017	0.075	0.023	0.058	0.006	0.010	0.014	0.030	0.071	0.014	0.006	0.009
0.027	0.025	0.113	0.090	0.066	0.123	0.051	0.043	0.012	0.026	0.013	0.006	0.009	0.061	0.102	0.074	0.021	0.008	0.031	0.039	0.010	0.143	0.022
0.011	0.004	0.023	0.210	0.092	0.058	0.083	0.084	0.077	0.132	0.053	0.171	0.051	0.068	0.022	0.049	0.074	0.029	0.073	0.013	0.122	0.141	0.055
0.003	0.054	0.006	0.020	0.053	0.104	0.003	0.037	0.064	0.014	0.014	0.032	0.043	0.028	0.034	0.002	0.022	0.036	0.091	0.073	0.056	0.021	0.009
0.034	0.020	0.056	0.048	0.035	0.032	0.042	0.105	0.029	0.103	0.010	0.015	0.051	0.073	0.038	0.050	0.013	0.032	0.008	0.027	0.048	0.017	0.021
0.031	0.057	0.029	0.124	0.119	0.105	0.022	0.066	0.001	0.069	0.021	0.008	0.081	0.018	0.028	0.066	0.061	0.100	0.004	0.029	0.028	0.008	0.010
0.041	0.036	0.012	0.024	0.032	0.017	0.007	0.033	0.005	0.020	0.007	0.018	0.015	0.066	0.048	0.007	0.004	0.011	0.020	0.052	0.006	0.039	0.053
0.026	0.003	0.086	0.078	0.018	0.004	0.041	0.030	0.027	0.018	0.029	0.018	0.079	0.062	0.025	0.022	0.026	0.059	0.004	0.015	0.033	0.005	0.011
0.011	0.099	0.072	0.041	0.054	0.075	0.064	0.075	0.013	0.023	0.024	0.013	0.059	0.037	0.013	0.028	0.066	0.093	0.009	0.118	0.059	0.006	0.020
0.065	0.045	0.007	0.063	0.023	0.146	0.135	0.065	0.052	0.129	0.027	0.010	0.027	0.011	0.007	0.075	0.105	0.010	0.003	0.017	0.004	0.025	0.020
0.043	0.006	0.039	0.065	0.124	0.070	0.066	0.064	0.023	0.031	0.034	0.138	0.050	0.035	0.067	0.084	0.039	0.006	0.010	0.011	0.034	0.040	0.066
0.025	0.041	0.091	0.023	0.055	0.041	0.044	0.048	0.023	0.030	0.044	0.012	0.076	0.084	0.012	0.058	0.028	0.039	0.019	0.003	0.042	0.084	0.002
0.022	0.011	0.034	0.110	0.086	0.171	0.074	0.071	0.122	0.055	0.067	0.028	0.044	0.025	0.028	0.023	0.038	0.091	0.032	0.076	0.006	0.083	0.074

Hurling Study – Constant Error Raw Data

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
-0.005	0.023	-0.007	0.046	-0.004	-0.032	0.020	0.021	-0.012	-0.006	0.056	0.022	-0.007	-0.023	-0.012	0.061	-0.003	0.010	-0.001	0.012
-0.051	-0.006	0.020	0.054	-0.156	0.039	-0.062	0.022	-0.103	0.054	0.026	0.054	0.031	-0.027	0.052	0.013	0.020	0.051	-0.027	0.065
0.030	-0.063	0.032	0.041	0.049	-0.075	0.050	-0.084	0.151	0.046	-0.013	-0.019	-0.016	0.009	0.116	-0.032	-0.056	0.047	-0.042	-0.019
-0.095	-0.053	-0.042	0.079	0.001	-0.023	-0.073	-0.019	-0.080	0.038	0.004	-0.064	-0.074	0.032	-0.093	0.033	0.046	-0.045	-0.035	0.048
-0.075	0.063	0.013	0.097	-0.026	-0.042	0.013	0.041	0.014	0.054	-0.006	0.059	-0.022	0.050	-0.010	0.039	0.072	0.024	-0.005	0.008
-0.058	0.043	-0.003	0.019	-0.094	0.011	-0.055	0.002	-0.027	0.069	-0.063	-0.017	0.004	-0.050	-0.059	0.041	-0.072	0.008	-0.034	-0.036
-0.036	0.026	0.007	0.046	0.021	-0.051	-0.002	0.036	-0.020	0.024	0.044	-0.060	0.091	0.040	0.027	0.006	0.023	0.026	-0.041	0.089
-0.054	-0.078	-0.018	-0.067	-0.072	-0.040	-0.034	-0.003	-0.048	-0.080	0.002	-0.010	-0.044	-0.037	0.018	-0.011	-0.016	-0.025	-0.024	-0.042
0.002	0.040	-0.046	-0.050	0.003	-0.063	-0.017	-0.026	0.084	-0.079	0.028	-0.148	-0.093	-0.066	-0.036	-0.113	-0.072	-0.145	-0.101	0.044
-0.044	0.013	0.053	0.059	0.091	0.137	0.036	-0.040	0.063	0.087	0.030	0.028	-0.015	0.044	0.113	0.157	-0.025	0.135	0.072	0.028
-0.029	0.117	-0.023	0.009	0.042	0.094	0.078	-0.050	0.030	0.017	0.034	-0.066	0.029	-0.009	0.038	0.037	-0.065	0.025	-0.074	0.022
-0.023	-0.017	0.009	0.058	-0.102	-0.014	0.019	-0.001	-0.063	-0.004	-0.026	0.045	-0.048	-0.001	-0.012	0.044	-0.076	-0.014	-0.022	0.057
-0.108	0.001	-0.067	0.010	-0.007	0.052	-0.021	0.023	-0.061	-0.010	0.014	-0.033	-0.002	0.021	-0.041	0.041	-0.051	0.043	-0.028	0.040
-0.022	0.055	-0.049	0.002	0.019	0.014	-0.003	-0.016	-0.025	0.051	-0.063	0.010	0.003	-0.006	0.022	0.019	-0.068	-0.027	0.009	0.015
-0.101	-0.115	0.031	0.017	0.027	0.002	-0.081	-0.078	-0.092	-0.041	-0.006	-0.029	0.020	0.029	-0.018	0.065	0.040	-0.004	0.003	-0.009
-0.023	-0.003	0.008	-0.003	0.078	-0.043	-0.018	-0.027	-0.035	-0.010	-0.016	0.001	0.021	0.005	-0.013	-0.024	0.005	-0.041	0.045	-0.068
-0.035	0.073	0.009	0.037	0.118	0.026	-0.077	0.019	0.068	-0.051	0.041	0.019	-0.013	-0.059	-0.079	0.052	0.026	-0.025	0.054	0.033
0.022	0.054	0.043	-0.027	0.065	-0.051	-0.084	-0.032	-0.056	-0.019	0.050	-0.009	0.033	0.046	-0.045	-0.035	0.048	0.079	0.003	0.038
0.076	0.082	0.014	-0.042	-0.036	-0.101	0.032	-0.046	0.081	-0.032	0.014	0.009	-0.019	-0.091	0.067	0.092	0.112	-0.052	-0.074	-0.081
-0.117	0.084	0.062	0.091	-0.080	-0.110	0.034	0.046	0.090	0.076	-0.081	-0.052	-0.041	-0.022	-0.009	-0.008	-0.042	0.031	0.019	-0.068

M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20
0.073	0.021	0.081	0.030	0.058	0.042	0.057	-0.033	0.097	0.044	0.051	-0.084	0.068	0.014	0.053	0.011	0.066	-0.013	0.045	-0.014
-0.057	-0.066	0.039	0.067	-0.029	0.027	-0.058	-0.031	0.005	0.079	0.015	0.075	-0.063	0.039	-0.074	0.032	0.005	0.015	-0.009	-0.004
-0.046	0.004	0.094	-0.117	-0.080	-0.052	0.043	0.012	0.002	-0.030	-0.047	-0.044	0.064	-0.043	0.069	-0.035	-0.038	0.046	-0.043	0.006
-0.093	-0.024	-0.003	0.011	-0.030	0.001	0.019	0.049	-0.001	-0.095	0.081	0.040	-0.041	-0.011	0.036	-0.014	-0.019	0.009	0.040	0.066
0.005	0.014	-0.012	0.026	-0.037	0.013	-0.023	0.123	-0.009	0.054	-0.089	0.024	-0.013	-0.045	-0.071	0.123	0.018	-0.054	0.024	0.061
-0.025	0.009	-0.002	-0.011	-0.030	-0.055	0.015	-0.008	-0.012	0.060	0.030	-0.058	-0.001	-0.010	-0.051	-0.003	-0.035	0.025	0.005	-0.039
-0.010	0.011	0.027	0.059	0.013	0.046	-0.068	-0.062	0.004	0.026	0.048	0.049	-0.039	0.021	0.020	0.027	-0.046	0.093	0.008	-0.012
-0.131	-0.100	-0.088	-0.078	-0.041	-0.002	-0.062	-0.011	-0.019	-0.067	-0.029	-0.055	-0.009	-0.080	-0.017	-0.003	-0.079	-0.050	0.045	-0.105
-0.071	-0.055	-0.023	-0.048	0.027	-0.024	-0.014	-0.019	-0.022	-0.039	-0.009	-0.051	-0.022	0.035	-0.006	-0.046	-0.058	-0.027	-0.025	-0.113
0.015	-0.020	0.036	-0.004	0.011	0.038	0.125	0.102	0.022	-0.006	-0.083	0.007	0.028	0.081	-0.095	0.050	-0.028	0.011	-0.004	-0.023
-0.047	0.078	0.006	-0.003	-0.098	-0.002	0.054	-0.084	-0.077	-0.001	0.003	-0.072	-0.010	0.066	0.021	0.068	-0.022	0.003	0.054	0.006
-0.027	0.014	0.013	0.029	0.006	0.036	-0.037	0.032	-0.036	0.037	-0.001	0.058	-0.029	0.055	-0.076	0.022	-0.007	-0.034	0.020	0.056
-0.122	-0.013	-0.038	0.009	-0.019	0.006	-0.010	0.023	-0.073	-0.044	-0.021	0.003	0.016	-0.003	-0.034	-0.014	0.051	-0.031	0.057	0.029
0.037	-0.018	-0.066	0.037	-0.079	-0.056	0.002	0.006	-0.034	-0.062	-0.048	0.003	0.016	0.090	-0.033	-0.038	0.022	-0.041	-0.036	0.012
-0.060	-0.071	-0.018	0.002	-0.042	-0.094	0.031	0.026	0.041	-0.032	-0.016	0.027	-0.019	-0.040	0.006	0.013	-0.005	0.026	0.003	0.086
0.036	0.023	0.056	0.091	-0.087	-0.042	0.048	-0.001	-0.134	0.039	0.057	0.030	-0.069	-0.012	0.100	-0.116	-0.018	-0.011	0.099	0.072
-0.081	-0.018	0.048	0.070	0.027	-0.075	0.088	-0.035	-0.005	-0.058	-0.043	-0.059	0.014	0.037	-0.033	-0.004	0.080	-0.065	0.045	-0.007
0.081	0.040	0.036	-0.014	-0.019	0.040	0.066	-0.024	-0.117	-0.080	-0.03	0.064	-0.043	0.069	-0.035	-0.038	0.046	-0.043	0.006	0.039
0.038	-0.006	-0.083	0.007	0.081	-0.095	-0.032	0.011	0.073	0.022	0.111	0.055	0.058	-0.084	0.036	0.107	0.072	-0.025	-0.041	-0.091
0.084	-0.019	0.080	-0.091	-0.081	-0.054	-0.049	-0.032	0.086	0.069	-0.029	-0.037	0.061	0.054	0.008	-0.017	-0.028	0.022	-0.011	0.034

H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20
0.025	-0.002	-0.006	0.007	-0.001	0.023	0.001	-0.020	0.011	-0.027	0.032	0.072	0.028	-0.008	-0.064	-0.021	-0.015	0.008	0.001	0.025
-0.077	0.064	0.022	0.023	-0.014	0.016	-0.032	0.024	-0.004	0.065	0.034	-0.129	0.041	0.038	0.070	0.071	-0.066	-0.022	0.064	-0.001
-0.093	0.012	-0.051	-0.024	-0.045	-0.023	-0.031	-0.031	-0.038	-0.023	0.031	-0.103	-0.044	0.004	0.012	-0.058	-0.008	-0.028	0.031	0.034
-0.176	0.048	-0.022	-0.022	-0.106	0.018	0.004	-0.012	0.138	0.017	0.156	-0.001	-0.050	-0.024	-0.053	0.037	-0.035	-0.004	-0.039	-0.006
0.003	0.068	0.003	0.049	-0.036	0.049	0.022	0.042	-0.028	-0.008	0.046	0.054	-0.017	0.053	-0.021	0.085	-0.005	-0.045	-0.015	0.064
-0.063	0.073	-0.037	-0.054	-0.035	-0.007	-0.013	0.028	-0.069	-0.013	-0.040	-0.010	0.006	-0.004	-0.007	0.033	-0.055	0.013	0.011	0.025
-0.102	0.069	0.010	0.026	0.002	-0.005	0.049	-0.039	0.059	0.056	-0.064	-0.047	0.022	0.040	-0.044	0.057	-0.002	0.035	-0.006	0.005
-0.059	-0.060	-0.051	-0.027	-0.133	-0.003	-0.008	0.014	-0.017	-0.075	-0.023	-0.058	-0.006	0.010	-0.014	-0.030	-0.071	0.014	0.006	-0.009
0.090	-0.066	-0.123	-0.051	-0.043	-0.012	-0.026	-0.013	-0.006	0.009	-0.061	-0.102	-0.074	-0.021	0.008	-0.031	-0.039	-0.010	-0.143	-0.022
-0.210	0.092	0.058	0.083	0.084	0.077	0.132	0.053	0.171	0.051	0.068	0.022	0.049	-0.074	0.029	0.073	-0.013	0.122	0.141	0.055
0.020	0.053	-0.104	0.003	-0.037	0.064	-0.014	0.014	0.032	0.043	0.028	0.034	0.002	0.022	-0.036	-0.091	0.073	-0.056	0.021	0.009
0.048	0.035	0.032	0.042	-0.105	0.029	0.103	-0.010	-0.015	0.051	-0.073	0.038	0.050	0.013	0.032	0.008	0.027	-0.048	-0.017	-0.021
-0.124	-0.119	-0.105	-0.022	-0.066	-0.001	0.069	0.021	-0.008	-0.081	0.018	0.028	-0.066	0.061	-0.100	-0.004	0.029	-0.028	-0.008	-0.010
0.024	-0.032	0.017	0.007	-0.033	0.005	-0.020	0.007	0.018	-0.015	-0.066	0.048	-0.007	-0.004	-0.011	0.020	-0.052	0.006	0.039	0.053
-0.078	-0.018	0.004	0.041	-0.030	-0.027	-0.018	-0.029	0.018	-0.079	-0.062	-0.025	0.022	-0.026	-0.059	-0.004	-0.015	0.033	-0.005	-0.011
0.041	-0.054	-0.075	-0.064	-0.075	-0.013	0.023	-0.024	0.013	-0.059	-0.037	-0.013	0.028	-0.066	-0.093	-0.009	-0.118	-0.059	0.006	-0.020
-0.063	-0.023	0.146	0.135	0.065	-0.052	-0.129	-0.027	-0.010	0.027	0.011	0.007	0.075	-0.105	-0.010	-0.003	0.017	-0.004	0.025	0.020
0.065	-0.124	0.070	-0.066	0.064	0.023	-0.031	0.034	0.138	-0.050	-0.035	-0.067	0.084	-0.039	-0.006	-0.010	0.011	-0.034	0.040	0.066
-0.023	-0.055	-0.041	-0.044	-0.048	0.023	0.031	-0.044	0.012	0.076	0.084	-0.012	-0.058	-0.028	0.039	-0.019	0.003	-0.042	-0.084	0.002
-0.110	0.086	0.171	-0.074	0.071	0.122	0.055	0.067	0.028	0.044	-0.025	-0.028	-0.023	0.038	0.091	0.032	0.076	-0.006	-0.083	-0.074

Hurling Study – Variable Error Raw Data

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
0.020	0.008	0.022	0.031	0.019	0.047	0.005	0.006	0.027	0.021	0.041	0.007	0.022	0.038	0.027	0.046	0.018	0.005	0.016	0.003
0.055	0.010	0.016	0.050	0.160	0.035	0.066	0.018	0.107	0.050	0.022	0.050	0.027	0.031	0.048	0.009	0.016	0.047	0.031	0.061
0.039	0.054	0.041	0.050	0.058	0.066	0.059	0.075	0.160	0.055	0.004	0.010	0.007	0.018	0.125	0.023	0.047	0.056	0.033	0.010
0.086	0.044	0.033	0.088	0.010	0.014	0.064	0.010	0.071	0.047	0.013	0.055	0.065	0.041	0.084	0.042	0.055	0.036	0.026	0.057
0.089	0.049	0.001	0.083	0.040	0.056	0.001	0.027	0.000	0.040	0.020	0.045	0.036	0.036	0.024	0.025	0.058	0.010	0.019	0.006
0.045	0.056	0.010	0.032	0.081	0.024	0.042	0.015	0.014	0.082	0.050	0.004	0.017	0.037	0.046	0.054	0.059	0.021	0.021	0.023
0.046	0.016	0.003	0.036	0.011	0.061	0.012	0.026	0.030	0.014	0.034	0.070	0.081	0.030	0.017	0.004	0.013	0.016	0.051	0.079
0.014	0.038	0.022	0.027	0.032	0.000	0.006	0.037	0.008	0.040	0.042	0.030	0.004	0.003	0.058	0.029	0.024	0.015	0.016	0.002
0.042	0.080	0.006	0.010	0.043	0.023	0.023	0.014	0.124	0.039	0.068	0.108	0.053	0.026	0.004	0.073	0.032	0.105	0.061	0.084
0.083	0.026	0.014	0.020	0.052	0.098	0.003	0.079	0.024	0.048	0.009	0.011	0.054	0.005	0.074	0.118	0.064	0.096	0.033	0.011
0.033	0.113	0.027	0.005	0.038	0.090	0.074	0.054	0.026	0.013	0.030	0.070	0.025	0.013	0.034	0.033	0.069	0.021	0.078	0.018
0.026	0.020	0.006	0.055	0.105	0.017	0.016	0.004	0.066	0.007	0.029	0.042	0.051	0.004	0.015	0.041	0.079	0.017	0.025	0.054
0.125	0.016	0.084	0.007	0.024	0.035	0.038	0.006	0.078	0.027	0.973	0.050	0.019	0.004	0.058	0.024	0.068	0.026	0.045	0.023
0.016	0.061	0.043	0.008	0.025	0.020	0.003	0.010	0.019	0.057	0.057	0.016	0.009	0.000	0.028	0.025	0.062	0.021	0.015	0.021
0.087	0.101	0.045	0.031	0.041	0.016	0.067	0.064	0.078	0.027	0.008	0.015	0.034	0.043	0.004	0.079	0.054	0.010	0.017	0.005
0.012	0.008	0.019	0.008	0.089	0.032	0.007	0.016	0.024	0.001	0.005	0.012	0.032	0.016	0.002	0.013	0.016	0.030	0.056	0.057
0.039	0.069	0.005	0.033	0.114	0.022	0.081	0.015	0.064	0.055	0.037	0.015	0.017	0.063	0.083	0.048	0.022	0.029	0.050	0.029
0.017	0.049	0.038	0.032	0.060	0.056	0.089	0.037	0.061	0.024	0.045	0.014	0.028	0.041	0.050	0.040	0.043	0.074	0.002	0.033
0.076	0.082	0.014	0.042	0.036	0.101	0.032	0.046	0.081	0.032	0.014	0.009	0.019	0.091	0.067	0.092	0.112	0.052	0.074	0.081
0.124	0.077	0.055	0.084	0.087	0.117	0.0270	0.039	0.083	0.069	0.088	0.059	0.048	0.029	0.016	0.015	0.049	0.024	0.012	0.075

M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**	**M13**	**M14**	**M15**	**M16**	**M17**	**M18**	**M19**	**M20**
0.058	0.006	0.066	0.015	0.043	0.027	0.042	0.048	0.082	0.029	0.036	0.099	0.053	0.001	0.038	0.004	0.051	0.028	0.030	0.029
0.061	0.070	0.035	0.063	0.033	0.023	0.062	0.035	0.001	0.075	0.011	0.071	0.067	0.035	0.078	0.028	0.001	0.011	0.013	0.008
0.037	0.013	0.103	0.108	0.071	0.043	0.052	0.021	0.005	0.021	0.038	0.035	0.073	0.034	0.078	0.026	0.029	0.055	0.034	0.015
0.084	0.015	0.006	0.020	0.021	0.010	0.028	0.058	0.008	0.086	0.090	0.049	0.032	0.002	0.045	0.005	0.010	0.018	0.049	0.075
0.009	0.000	0.026	0.012	0.051	0.001	0.037	0.109	0.023	0.040	0.103	0.010	0.027	0.059	0.085	0.109	0.004	0.068	0.010	0.047
0.012	0.022	0.011	0.002	0.017	0.042	0.028	0.005	0.001	0.073	0.043	0.045	0.012	0.003	0.038	0.010	0.022	0.038	0.018	0.026
0.020	0.001	0.017	0.049	0.003	0.036	0.078	0.072	0.006	0.016	0.038	0.039	0.049	0.011	0.010	0.017	0.056	0.083	0.002	0.022
0.091	0.060	0.048	0.038	0.001	0.038	0.022	0.029	0.021	0.027	0.011	0.015	0.031	0.040	0.023	0.037	0.039	0.010	0.085	0.065
0.031	0.015	0.017	0.087	0.067	0.016	0.026	0.021	0.018	0.001	0.031	0.011	0.018	0.075	0.034	0.006	0.018	0.013	0.015	0.073
0.024	0.059	0.003	0.043	0.028	0.001	0.086	0.063	0.017	0.045	0.122	0.032	0.011	0.042	0.134	0.011	0.067	0.028	0.043	0.062
0.051	0.074	0.002	0.007	0.102	0.006	0.050	0.088	0.081	0.005	0.001	0.076	0.014	0.062	0.017	0.064	0.026	0.001	0.050	0.002
0.030	0.011	0.010	0.026	0.003	0.033	0.040	0.029	0.039	0.034	0.004	0.055	0.032	0.052	0.079	0.019	0.010	0.037	0.017	0.053
0.139	0.030	0.055	0.008	0.036	0.011	0.027	0.006	0.090	0.061	0.939	0.014	0.001	0.020	0.051	0.031	0.034	0.048	0.040	0.012
0.043	0.012	0.060	0.043	0.073	0.050	0.008	0.012	0.028	0.056	0.042	0.009	0.022	0.096	0.027	0.032	0.028	0.035	0.030	0.018
0.046	0.057	0.004	0.016	0.028	0.080	0.045	0.040	0.055	0.018	0.002	0.041	0.005	0.026	0.020	0.027	0.009	0.040	0.017	0.100
0.047	0.034	0.067	0.102	0.076	0.031	0.059	0.010	0.123	0.050	0.068	0.041	0.058	0.001	0.111	0.105	0.007	0.000	0.110	0.083
0.085	0.022	0.044	0.066	0.023	0.079	0.084	0.039	0.009	0.062	0.047	0.063	0.010	0.033	0.037	0.008	0.076	0.069	0.041	0.011
0.076	0.035	0.031	0.019	0.024	0.035	0.061	0.029	0.122	0.085	0.035	0.059	0.048	0.064	0.040	0.043	0.041	0.048	0.001	0.034
0.038	0.006	0.083	0.007	0.081	0.095	0.032	0.011	0.073	0.022	0.111	0.055	0.058	0.084	0.036	0.107	0.072	0.025	0.041	0.091
0.077	0.026	0.073	0.098	0.088	0.061	0.056	0.039	0.079	0.062	0.036	0.044	0.054	0.047	0.001	0.024	0.035	0.015	0.018	0.027

H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20
0.010	0.017	0.021	0.008	0.016	0.008	0.014	0.035	0.004	0.042	0.017	0.057	0.013	0.023	0.079	0.036	0.030	0.007	0.014	0.010
0.081	0.060	0.018	0.019	0.018	0.012	0.036	0.020	0.008	0.061	0.030	0.133	0.037	0.034	0.066	0.067	0.070	0.026	0.060	0.005
0.084	0.021	0.042	0.015	0.036	0.014	0.022	0.022	0.029	0.014	0.040	0.094	0.035	0.013	0.021	0.049	0.001	0.019	0.040	0.043
0.167	0.057	0.013	0.013	0.097	0.027	0.013	0.003	0.147	0.026	0.165	0.008	0.041	0.015	0.044	0.046	0.026	0.005	0.030	0.003
0.011	0.054	0.011	0.035	0.050	0.035	0.008	0.028	0.042	0.022	0.032	0.040	0.031	0.039	0.035	0.071	0.019	0.059	0.029	0.050
0.050	0.086	0.024	0.041	0.022	0.006	0.000	0.041	0.056	0.000	0.027	0.003	0.019	0.009	0.006	0.046	0.042	0.026	0.024	0.038
0.112	0.059	0.000	0.016	0.008	0.015	0.039	0.049	0.049	0.046	0.074	0.057	0.012	0.030	0.054	0.047	0.012	0.025	0.016	0.005
0.019	0.020	0.011	0.013	0.093	0.037	0.032	0.054	0.023	0.035	0.017	0.018	0.034	0.050	0.026	0.010	0.031	0.054	0.046	0.031
0.130	0.026	0.083	0.011	0.003	0.028	0.014	0.027	0.034	0.049	0.021	0.062	0.034	0.019	0.048	0.009	0.001	0.030	0.103	0.018
0.249	0.053	0.019	0.044	0.045	0.038	0.093	0.014	0.132	0.012	0.029	0.017	0.010	0.113	0.010	0.034	0.052	0.083	0.102	0.016
0.016	0.049	0.108	0.001	0.041	0.060	0.018	0.010	0.028	0.039	0.024	0.030	0.002	0.018	0.040	0.095	0.069	0.060	0.017	0.005
0.045	0.032	0.029	0.039	0.108	0.026	0.100	0.013	0.018	0.048	0.076	0.035	0.047	0.010	0.029	0.005	0.024	0.051	0.020	0.024
0.141	0.136	0.122	0.039	0.083	0.018	0.052	0.004	0.025	0.098	0.001	0.011	0.083	0.044	0.117	0.021	0.012	0.045	0.025	0.027
0.030	0.026	0.023	0.013	0.027	0.011	0.014	0.013	0.024	0.009	0.060	0.054	0.001	0.002	0.005	0.026	0.046	0.012	0.045	0.059
0.064	0.004	0.018	0.055	0.016	0.013	0.004	0.015	0.032	0.065	0.048	0.011	0.036	0.012	0.045	0.010	0.001	0.047	0.009	0.003
0.052	0.043	0.064	0.053	0.064	0.002	0.034	0.013	0.024	0.048	0.026	0.002	0.039	0.055	0.082	0.002	0.107	0.048	0.017	0.009
0.067	0.027	0.142	0.131	0.061	0.056	0.133	0.031	0.014	0.023	0.007	0.003	0.071	0.109	0.014	0.007	0.013	0.008	0.021	0.016
0.060	0.129	0.065	0.071	0.059	0.018	0.036	0.029	0.133	0.055	0.040	0.072	0.079	0.044	0.011	0.015	0.006	0.039	0.035	0.061
0.023	0.055	0.041	0.044	0.048	0.023	0.031	0.044	0.012	0.076	0.084	0.012	0.058	0.028	0.039	0.019	0.003	0.042	0.084	0.002
0.103	0.093	0.178	0.067	0.078	0.129	0.062	0.074	0.035	0.051	0.018	0.021	0.016	0.045	0.098	0.039	0.083	0.001	0.076	0.067

Stroop Study – Raw Data

Height	Weight	RHR	HRR 70	HRR 90	TTF 70	TTF 90	Test Rest	Errors Rest	PS 70	Errors 70	PS 90	Errors 90
184.5	80	48	180	185	6.2	9.11	26.909	1	25.376	0	27.49	0
175	105	70	179	187	5.4	6	22.202	0	21.451	1	22.342	0
181	99	65	170	178	5.4	8.15	20.089	1	18.847	0	19.088	1
182	67	55	136	175	5.35	9.06	22.37	1	22.863	0	23.694	0
184	74	45	155	163	6.4	13.5	23.704	0	21.752	1	24.896	1
181.5	67.5	68	161	180	7.07	10	19.598	1	19.1	0	21.171	0
184	84.4	54	161	190	7	8.45	20.399	0	25.146	1	22.142	0
185	93	55	160	175	7.3	10.15	19.629	0	18.737	1	19.959	0
174.5	70.5	75	182	210	7.4	10	20.199	1	23.555	1	23.395	1
174.5	70	55	173	188	6.15	7.11	21.06	2	20.509	3	23.34	1
179	75	51	167	192	6.5	10.1	23.089	0	22.847	0	24.103	0
186	85	58	168	191	6.09	9.15	26.707	0	25.21	0	28.426	0

Tennis Study – Raw Data

Expertise	M1F2	Age	Height	Weight	Mapp	Mavoid	Papp	Pavoid	App Avg	Hi/LoApp	Avoid Avg	Hi/Lo Avoid	PeakHR	HRRest	HR70	HR90	TTF70	TTF90
2	1	28	184.5	76.1	6	2	2.67	2	4.33	2	2	2	178	104	147	171	11	21
1	1	18	172.5	71.3	6	2.3	6.3	2	6.16	1	2.16	2	187	110	164	177	9	17
1	1	17	177.5	67.6	7	3.67	6	2.3	6.5	1	3	2	184	115	167	189	12	20
1	1	14	171.5	63.4	5.33	1.67	2.3	1.3	3.83	2	1.5	2	186	125	176	178	8	11
1	2	26	161.5	53.1	6	3.3	4.3	3.67	5.16	2	3.5	2	175	118	170	184	8	15
2	1	21	183	70.9	6.67	2.3	7	2	6.83	1	2.16	2	189	122	173	194	4	7
1	1	19	187	78	7	2.3	5	1.67	6	1	2	2	172	120	172	187	4	8
2	1	49	181	65.2	7	5.3	5.67	3	6.33	1	4.16	1	162	128	161	172	6	10
2	2	18	170	62.2	4.33	1.3	6.67	3.3	5.5	2	2.33	2	182	126	165	184	7	10
1	1	19	189	76	6.67	2	6	2	6.33	1	2	2	179	134	170	180	9	17
1	2	18	166	56.2	7	1.3	6.67	1	6.83	1	1.16	2	180	135	176	188	7	12
2	1	25	181	77.8	7	6.3	7	7	7	1	6.66	1	204	114	179	200	4	8
2	1	19	183	73.7	6.33	6.67	3.67	5.67	5	2	6.16	1	173	127	173	192	5	19
1	1	19	181.5	72.4	5.67	5	5	6	5.33	2	5.5	1	170	107	175	190	4	9
2	2	20	169	50.7	5.67	7	3.3	2.3	4.5	2	4.66	1	178	129	177	193	4	10
1	2	24	176.5	83.9	5.33	7	5.67	1.3	5.5	2	4.16	1	190	90	173	192	7	12
1	2	19	178	99.4	5.67	2.67	6	4.3	5.83	1	3.5	2	189	124	169	187	4	8
2	1	21	182	66.6	5.67	7	5	6.3	5.33	2	6.66	1	188	121	177	190	5	12
2	2	20	172	59.8	5.67	5.3	4	3.3	4.83	2	4.33	1	190	128	171	184	4	8
1	1	19	174	58.5	6.67	5.3	3.67	5	5.16	2	5.16	1	172	135	164	184	6	15
2	1	20	187	75.9	5.67	2	2.3	4.67	4	2	3.33	2	190	120	170	183	5	11
2	1	18	194	73.3	6	5	6	5.67	6	1	5.33	1	196	125	177	195	6	14
1	2	21	176	58.3	5.33	5.3	5.3	4.67	5.33	2	5	1	190	132	174	183	5	10
2	2	27	156	57	6.67	7	5.67	3	6.16	1	5	1	190	140	178	194	5	12
2	1	19	183	68.5	6	3	6.67	3.67	6.33	1	3.33	2	200	129	178	192	8	21
1	2	20	176	87.8	7	6.67	1.3	1.3	4.16	2	4	1	191	122	176	196	7	18
2	1	48	177	94.2	6.67	3.3	5.3	6.3	6	1	4.83	1	181	129	154	171	7	11
2	1	30	174	87	7	2	7	1	7	1	1.5	2	185	119	168	184	5	12
2	1	21	187	98	7	5.67	5	2	6	1	3.83	1	189	125	174	192	5	13
2	1	20	196	88.2	4	3.3	4.67	5.3	4.33	2	4.33	1	188	141	170	191	6	11

DTLF%OR	DTLF%CR	DTLF%IR	DTLB%OR	DTLB%CR	DTLB%IR	CCF%OR	CCF%CR	CCF%IR	CCB%OR	CCB%CR	CCB%IR	DTLF%O70
20	20	60	30	30	40	20	50	30	40	60	0	20
10	70	20	10	50	40	20	60	20	20	70	10	10
20	50	30	30	60	10	30	30	40	30	10	60	10
10	40	50	20	40	40	10	50	40	20	50	30	0
20	40	40	30	70	0	30	60	10	50	50	0	50
30	30	40	70	30	0	10	90	0	40	60	0	20
30	30	40	20	70	10	30	50	20	10	20	70	40
30	50	20	70	20	10	20	70	10	50	30	20	10
70	20	10	70	20	10	50	30	20	60	30	10	70
10	40	50	20	70	10	10	40	50	20	70	10	10
10	50	40	20	70	10	0	60	40	10	70	20	0
0	20	80	10	70	20	10	30	60	40	50	10	40
70	20	10	80	10	10	60	40	0	60	20	20	40
0	90	10	40	30	30	50	40	10	40	60	0	30
30	30	40	40	40	20	10	80	10	40	50	10	40
10	60	30	0	80	20	10	70	20	0	100	0	40
20	60	20	20	50	30	30	50	20	30	70	0	10
70	20	10	40	10	50	90	10	0	50	20	30	60
50	40	10	40	50	10	50	40	10	30	60	10	80
20	30	50	50	10	40	20	40	40	50	40	10	0
30	30	40	60	30	10	10	60	30	40	50	10	50
10	80	10	50	30	20	60	40	0	60	40	0	20
50	20	30	20	40	40	20	50	30	20	70	10	20
30	60	10	40	30	30	30	60	10	30	50	20	60
30	70	0	30	50	20	50	50	0	50	40	10	70
20	60	20	30	70	0	30	50	20	40	60	0	20
40	60	0	60	40	0	20	80	0	40	50	10	50
30	60	10	40	40	20	50	30	20	30	50	20	40
30	40	30	30	60	10	50	30	20	10	60	30	30
20	70	10	80	20	0	40	40	20	80	10	10	10

DTLF%C70	DTLF%I70	DTLB%O70	DTLB%C70	DTLB%I70	CCF%O70	CCF%C70	CCF%I70	CCB%O70	CCB%C70	CCB%I70	DTLF%O90	DTLF%C90
50	30	30	40	30	20	50	30	0	30	70	60	40
80	10	50	40	10	20	60	20	10	70	20	40	60
60	30	30	70	0	40	20	40	20	50	30	50	50
80	20	50	30	20	20	60	20	30	30	40	30	60
30	20	40	60	0	40	20	40	30	60	10	40	60
50	30	10	70	20	20	60	20	30	60	10	50	50
30	30	40	60	0	30	40	30	10	50	40	50	50
80	10	60	40	0	20	60	20	50	30	20	40	40
20	10	60	30	10	20	60	20	50	50	0	50	40
30	60	10	60	30	10	50	40	10	60	30	30	50
40	60	10	50	40	0	60	40	10	60	30	30	50
50	10	20	50	30	20	60	20	20	50	30	40	30
50	10	30	40	30	70	30	0	30	30	40	60	20
50	20	20	60	20	40	50	10	20	60	20	20	70
30	30	60	40	0	0	80	20	10	80	10	80	20
30	30	20	50	30	30	60	10	20	50	30	40	60
60	30	60	40	0	10	90	0	30	50	20	10	60
30	10	30	60	10	50	40	10	10	50	40	60	30
10	10	30	60	10	70	30	0	20	60	20	80	10
60	40	30	40	30	40	50	10	30	50	20	50	40
40	10	40	40	20	30	20	50	60	30	10	80	10
80	0	80	10	10	50	40	10	60	30	10	50	40
70	10	40	50	10	10	70	20	30	20	50	30	60
40	0	60	30	10	40	40	20	20	60	20	50	50
30	0	60	40	0	40	60	0	40	50	10	50	50
30	50	40	40	20	20	70	10	0	50	50	50	30
40	10	60	40	0	30	70	0	60	40	0	50	40
50	10	20	60	20	30	50	20	20	60	20	80	20
50	20	30	30	40	40	40	20	0	90	10	50	50
70	20	40	40	20	20	50	30	50	40	10	50	40

DTLF%I90	DTLB%O90	DTLB%C90	DTLB%I90	CCF%O90	CCF%C90	CCF%I90	CCB%O90	CCB%C90	CCB%I90	FoutR	FconsisR	FinR	BoutR
0	50	50	0	10	70	20	70	30	0	20	35	45	35
0	20	40	40	40	60	0	40	40	20	15	65	20	15
0	60	30	10	30	60	10	50	50	0	25	40	35	30
10	40	20	40	10	80	10	70	20	10	10	45	45	20
0	50	40	10	80	20	0	40	50	10	25	50	25	40
0	30	50	20	70	20	10	40	40	20	20	60	20	55
0	30	40	30	0	40	60	30	40	30	30	40	30	15
20	60	30	10	30	60	10	90	10	0	25	60	15	60
10	70	30	0	70	30	0	60	40	0	60	25	15	65
20	50	50	0	30	50	20	30	60	10	10	40	50	20
20	40	50	10	30	50	20	30	70	0	5	55	40	15
30	40	50	10	30	50	20	40	20	40	5	25	70	25
20	50	30	20	30	60	10	60	10	30	65	30	5	70
10	40	60	0	30	60	10	60	30	10	25	65	10	40
0	60	30	10	30	50	20	40	50	10	25	55	25	40
0	20	60	20	20	80	0	10	90	0	10	65	25	0
30	20	40	40	30	60	10	40	30	30	25	55	20	25
10	20	30	50	80	10	10	30	60	10	80	15	5	45
10	70	20	10	50	50	0	30	70	0	50	40	10	35
10	50	50	0	60	20	20	40	20	40	20	35	45	50
10	30	50	20	70	30	0	100	0	0	20	45	35	50
10	40	60	0	70	20	10	60	40	0	35	60	5	55
10	50	50	0	10	70	20	10	70	20	35	35	30	20
0	50	50	0	60	40	0	80	20	0	30	60	10	35
0	50	30	20	70	20	10	50	50	0	40	60	0	40
20	20	40	40	20	60	20	30	50	20	25	55	20	35
10	80	10	10	50	50	0	80	20	0	30	70	0	50
0	90	10	0	50	50	0	70	30	0	40	45	15	35
0	60	40	0	40	50	10	40	50	10	40	35	25	20
10	100	0	0	50	50	0	90	10	0	30	55	15	80

BconsisR	BinR	Fout70	Fconsis70	Fin70	Bout70	Bconsis70	Bin70	Fout90	Fconsis90	Fin90	Bout90	Bconsis90	Bin90	AlloutR	AllconsisR
45	20	20	50	30	15	35	50	35	55	10	60	40	0	27.5	40
60	25	15	70	15	30	55	15	40	60	0	30	40	30	15	62.5
35	35	25	40	35	25	60	15	40	55	5	55	40	5	27.5	37.5
45	35	10	70	20	40	30	30	20	70	10	55	20	25	15	45
60	0	45	25	30	35	60	5	60	40	0	45	45	10	32.5	55
45	0	20	55	25	20	65	15	60	35	5	35	45	20	37.5	52.5
45	40	35	35	30	25	55	20	25	45	30	30	40	30	22.5	42.5
25	15	15	70	15	55	35	10	35	50	15	75	20	5	42.5	42.5
25	10	45	40	15	55	40	5	60	35	5	65	35	0	62.5	25
70	10	10	40	50	10	60	30	30	50	20	40	55	5	15	55
70	15	0	50	50	10	55	35	30	50	20	35	60	5	10	62.5
60	15	30	55	15	20	50	30	35	40	25	40	35	25	15	42.5
15	15	55	40	5	30	35	35	45	40	15	55	20	25	67.5	22.5
45	15	35	50	15	20	60	20	25	65	10	50	45	5	32.5	55
45	15	20	55	25	35	60	5	55	35	10	50	40	10	32.5	50
90	10	35	45	20	20	50	30	30	70	0	15	75	10	5	77.5
60	15	10	75	15	45	45	10	20	60	20	30	35	35	25	57.5
15	40	55	35	10	20	55	25	70	20	10	25	45	30	62.5	15
55	10	75	20	5	25	60	15	65	30	5	50	45	5	42.5	47.5
25	25	20	55	25	30	45	25	55	30	15	45	35	20	35	30
40	10	40	30	30	50	35	15	75	20	5	65	25	10	35	42.5
35	10	35	60	5	70	20	10	60	30	10	50	50	0	45	47.5
55	25	15	70	15	35	35	30	20	65	15	30	60	10	27.5	45
40	25	50	40	10	40	45	15	55	45	0	65	35	0	32.5	50
45	15	55	45	0	50	45	5	60	35	5	50	40	10	40	52.5
65	0	20	50	30	20	45	35	35	45	20	25	45	30	30	60
45	5	40	55	5	60	40	0	50	45	5	80	15	5	40	57.5
45	20	35	50	15	20	60	20	65	35	0	80	20	0	37.5	45
60	20	35	45	20	15	60	25	45	50	5	50	45	5	30	47.5
15	5	15	60	25	45	40	15	50	45	5	95	5	0	55	35

AllinR	Allout70	Allconsis70	Allin70	Allout90	Allconsis90	Allin90
32.5	17.5	42.5	40	47.5	47.5	5
22.5	22.5	62.5	15	35	50	15
35	25	50	25	47.5	47.5	5
40	25	50	25	37.5	45	17.5
12.5	40	42.5	17.5	52.5	42.5	5
10	20	60	20	47.5	40	12.5
35	30	45	25	27.5	42.5	30
15	35	52.5	12.5	55	35	10
12.5	50	40	10	62.5	35	2.5
30	10	50	40	35	52.5	12.5
27.5	5	52.5	42.5	32.5	55	12.5
42.5	25	52.5	22.5	37.5	37.5	25
10	42.5	37.5	20	50	30	20
12.5	27.5	55	17.5	37.5	55	7.5
20	27.5	57.5	15	52.5	37.5	10
17.5	27.5	47.5	25	22.5	72.5	5
17.5	27.5	60	12.5	25	47.5	27.5
22.5	37.5	45	17.5	47.5	32.5	20
10	50	40	10	57.5	37.5	5
35	25	50	25	50	32.5	17.5
22.5	45	32.5	22.5	70	22.5	7.5
7.5	52.5	40	7.5	55	40	5
27.5	25	52.5	22.5	25	62.5	12.5
17.5	45	42.5	12.5	60	40	0
7.5	52.5	45	2.5	55	37.5	7.5
10	20	47.5	32.5	30	45	25
2.5	50	47.5	2.5	65	30	5
17.5	27.5	55	17.5	72.5	27.5	0
22.5	25	52.5	22.5	47.5	47.5	5
10	30	50	20	72.5	25	2.5